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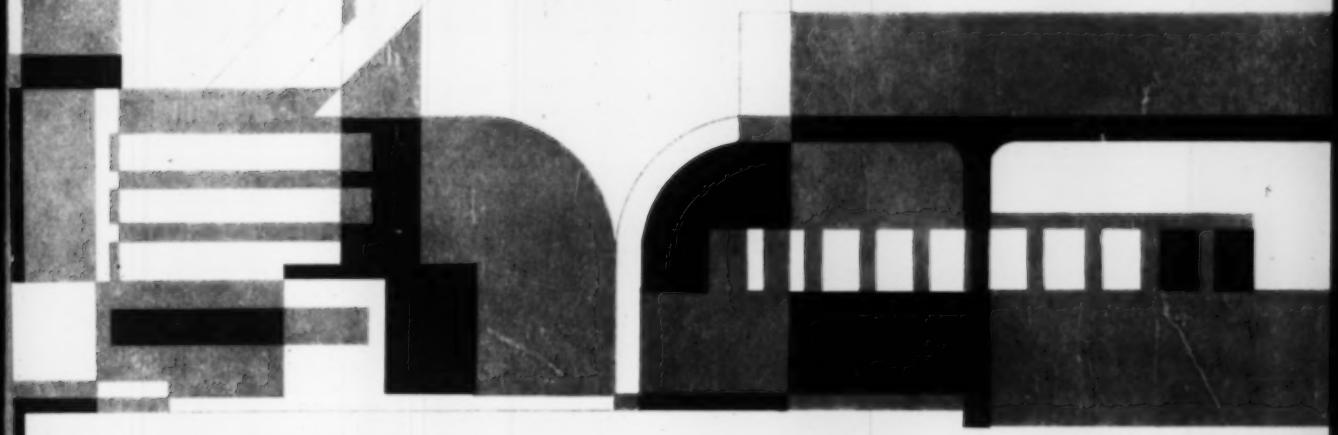

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Industrial Engineering—Training for Management*

by HAROLD B. MAYNARD

President, H. B. Maynard and Company, Inc., Pittsburgh

IT IS probably safe to say that the majority of Industrial Engineers, while enjoying their Industrial Engineering work immensely, look forward to future promotions to higher level and better paid work within the organization of which they are a part. In this they are no different than other ambitious people in the company who hope through hard work and meritorious performance on their present jobs to earn future advancement.

The logical path of promotion for the Industrial Engineer is into the ranks of management, that is into the work of managing where he becomes responsible for getting results by directing the efforts of other people. What chance does the Industrial Engineer have for getting this promotion? Is there anything about his Industrial Engineering work which especially trains him to manage? Is he any better qualified to become a manager than other bright young men who are coming up through other functional activity areas?

A number of years ago, a friend of mine had the task of installing an Industrial Engineering department in the company where he was working at the time. There were no trained Industrial Engineers available, or perhaps I should say time study men for that's about all Industrial Engineers were in those days, so he had to make them. He selected the best men he could find from the apprentice department, the shop floor, and anywhere else that bright young men were available. He developed a training course, trained the people he had selected, and presently had a time study department in operation.

Not long after this, my friend left the company, and it was nearly ten years before he had an opportunity to return to it for a visit. When he did, he was very much interested to find that four of the five divisional superintendents were men whom he had originally selected and trained for Industrial Engineering work.

Was this just mere coincidence? Did my friend have some unusual ability for picking good men? Or was there something about Industrial Engineering work even in the embryonic form in which it was then practiced that trained a man for greater managerial responsibilities later on?

I am convinced that the latter is the case. The incident I have described is by no means an isolated incident. Throughout industry, the Industrial Engineering department has come to be regarded as the training ground for future managers. Management has sensed that good replacement material for itself is to be found in the Industrial Engineering department, perhaps without even asking itself why. But there is a reason, and it will help the Industrial Engineer in his own career development if he understands what it is.

CHARACTERISTICS

The most obvious apparent reason is that people of high intelligence are attracted to Industrial Engineering work. High intelligence is required for the successful managing of other people, so superficially this would seem to be a logical reason for turning to the Industrial Engineering department when seeking new managers. But there are many people of high intelligence working in other functional areas too who somehow do not seem to be quite such logical candidates for managerial work as Industrial Engineers. It is true that managers have been selected from among purchasing agents, accountants, salesmen, design engineers, quality control men, tool designers, personnel men, and other functional activities, but the frequency with which this is done is by no means as great as in the case of Industrial Engineers. There must be something about Industrial Engineering, therefore, that fits a man for managing work to a greater extent than do many other functional activities.

The next thought that might occur to us is that Industrial Engineers make good managers because Industrial Engineering as originally developed by Taylor, the Gilbreths, and others became the foundation on which scientific management was built. There is to be sure a close affinity between Industrial Engineering and scientific management, but the terms are by no means synonymous as so many Industrial Engineers are inclined to think. So we shall have to search further to find why Industrial Engineers so often make good managers.

Recent research carried on in the Association of Consulting Management Engineers (ACME) may help to throw some light on the subject of our discussion today. A small committee last year made an intensive study of

*Based upon a presentation to the Fourth Annual Management Conference of the Ft. Wayne Chapter of AIIE, May 1, 1958.

the task of managing. The purpose of this study was to identify the knowledge a man must have to be able to consult effectively on a professional level with the managers of business and industry. The results of this study served that purpose, but they will also enable us to see why it is that experience in the field of Industrial Engineering helps train a man to manage.

According to the ACME committee, the task of managing may be described as a three-step process as follows:

1. Establish objectives
2. Direct the attainment of objectives
3. Measure results

This managing process is accomplished by employing what the committee has called the elements of managing. There are eleven of these elements.

I am now going to discuss briefly each of these eleven elements of managing in turn to see if experience in Industrial Engineering helps a man learn how to perform them skillfully. You might like to keep score on this as we go along. If you would, take any piece of paper you have handy. On the left-hand side write as a column heading "Element of Managing." On the right-hand side put down the column heading "Training Provided by Industrial Engineering." Then subdivide this last column into three columns which we shall head "Good," "Partial," and "Insufficient."

It is quite obvious that a scoring system of this sort can only be an approximation. Furthermore you may not entirely agree with my own scoring.

We do not define Industrial Engineering the same way, and our judgments are bound to be tempered by our own personal experience with Industrial Engineering and the Industrial Engineers we have known. Nevertheless we shall perhaps be able to agree in general with the conclusions to which our analysis will lead us.

GATHER INFORMATION

The first element of managing listed by the ACME committee is "gather information." I doubt if we would have any disagreement on this one. The Industrial Engineer is a trained information gatherer. A large part of his work consists of gathering factual information about what is going on. He is usually largely concerned with the facts which exist in the factory or department in which he works and may, when he becomes a manager, need to expand the areas in which he gathers information to include such things as sales and marketing influences, economic conditions, and the like. But as far as the training provided by Industrial Engineering for gathering information is concerned, we can unhesitatingly rate it as "good."

SYNTHESIZE

The second element of managing is "synthesize information." The information gathered by the Industrial Engineer on a specific problem in a narrow area may be quite complete. In the broader area of managing this is often not the case. The information obtainable on a situation of any complexity is seldom complete. The manager must take the bits and pieces he has and put them together to form a complete picture, filling in the gaps on the basis of past experience, imagination, or just plain hunch. The ability to synthesize differs greatly among individuals and is one of the distinguishing characteristics of a good manager. Some people have the ability to synthesize from incomplete data and others do not.

We perhaps do not know as much as we would like to about how the ability to synthesize may be developed, but in all probability Industrial Engineering work is not especially helpful in this connection. Indeed it may be just the opposite, for it tends to concentrate attention on the specific and the measurable, and tends to overlook the intangibles and the unmeasurables. Clarence Randall presented a series of lectures a few years ago in which he made a good case for a liberal arts education as being more useful than an engineering education for developing the ability to synthesize. At the same time, he did not write off the value of an engineering background and neither should we. Let's rate the training provided by Industrial Engineering in developing skill in synthesizing as "partial."

PLAN

The next element is "plan." The ability to plan is undoubtedly enhanced by Industrial Engineering experience. The Industrial Engineer gets facts in depth and establishes a clear picture of what the existing situation is. His foremost objective is to make the situation better. He is trained in a variety of methods improvement techniques, any or all of which may be used in a given situation. There are many things that might be done, so he visualizes what the various alternatives might be and considers what would have to be done to carry them out. Improvement in a manufacturing process, for example, may be made by anything from improving a few motion patterns to building a new and fully automated plant. The Industrial Engineer must consider these various alternatives, plan what might be done and how, and consider costs and economic benefits. This is quite similar to the kind of planning work he will have to do as a manager, and therefore we can record a check mark in the "good" column on our score sheet.

DECIDE

The fourth element of managing is "decide." There comes a time in the planning process when one of the alternatives must be decided upon. The Industrial Engineer is accustomed to weighing the pros and cons, the advantages and disadvantages, and the costs and savings of each alternative and selecting the one which seems to be the best course to follow. To this extent, his work trains him to decide.

The final decision, however, and the full responsibility for the consequences are not his. Usually when he has made his decision, he prepares a report giving his recommendations. The manager checks his work, asks questions, suggests other alternatives, and so on before finally deciding. When the decision is made, it is the manager who bears the direct responsibility for the results, not the Industrial Engineer. The Industrial Engineer, therefore, leads a somewhat sheltered life. He recommends, but he expects his recommendations to be checked by someone higher up. One of the duties which some Industrial Engineers find most difficult when they become managers is the making of the final decisions on which the fortunes of the company must rise or fall. The ability to assume the responsibility for important final decisions must be possessed by a line manager, but it is not usually required of a staff Industrial Engineer. Therefore, the training provided in decision making by Industrial Engineering work will have to be rated as "insufficient."

ORGANIZE

The fifth element of managing is "organize." Here the Industrial Engineer measures up well. He is by training an organizer. He organizes men, machinery, and materials in order to get the most effective results. He has an orderly type of mind which abhors chaos and insists on well organized activity. Thus his training in this area is useful to him when he becomes a manager. His approach as an engineer may be quite mechanistic and may need to be broadened to include consideration of people problems, where emotional, political, and other matters involving human vagaries enter in. In general, however, we may rate his training in organization as "good."

COMMUNICATE

The next element is "communicate." Certainly the Industrial Engineer recognizes the necessity of communicating his plans, suggestions, and recommendations to others. Indeed a good part of his work is communications. His reports, instruction sheets, and records are used to communicate about his work to others. He may or may not be effective, however, in his verbal communications. Furthermore, his training is in the area of communications about tangibles. They are factual, often dull, and usually lacking in inspiration. As a manager he will have to communicate about intangibles such as goals, aspirations, distant or idealistic objectives, and the like. And he will have to communicate clearly in language which will be understood by those he is communicating with, which is by no means easy when dealing with intangibles. With this in mind, the best rating we can give Industrial Engineering with respect to training in communications is "partial."

MOTIVATE

Next on our list of elements of managing comes "motivate." The Industrial Engineer is quite familiar with the problem of motivating people to do their best. Indeed, he deals daily with the problem of getting each worker to use approved methods and to continue to use them steadily all day long with a good working effort. The way he most commonly accomplishes this is through the use of incentive wage payment.

Financial incentives are certainly an important motivating force. But so too are non-financial incentives which the manager must use even more than financial incentives. The Industrial Engineer turned manager must learn to use the motivational forces provided by such things as inspiring ideals, recognition and prestige, identification with a worthwhile cause or project, and the opportunity to wield power. The skilled manager uses emotional factors to motivate his people, factors which may differ for each person he supervises. Because he deals so much in facts, the Industrial Engineer has to develop skill in using emotional incentives when he becomes a manager. His previous training gives him only "partial" skill in motivational techniques, and we must so record it on our score card.

DIRECT, GUIDE AND COUNSEL

The next element of managing, number 8, is "direct, guide, or counsel." This is the element that provides leadership during the performance of the work. The Industrial Engineer does not customarily do much of this in connection with his Industrial Engineering work. He gathers and synthesizes facts, plans and decides on or at least recommends improvements, organizes the work and tells others about it, and motivates people to do it by the use of standards, performance controls, and often wage incentives, but once this framework has been established, he usually leaves it to the line supervisor to see that the work actually gets done.

The line supervisor takes over at this point and through giving suggestions, orders, or additional information or by teaching how the work is to be accomplished sees that the established objectives get carried out. Thus Industrial Engineering work does not provide leadership training to any great extent, at least insofar as direct leadership aimed at getting specific tasks done is concerned. We must give the rating of "insufficient" for the element of "direct, guide, or counsel," for this is one of the elements of managing the Industrial Engineer must learn a good deal more about when he becomes a manager.

MEASURE, EVALUATE AND CONTROL

The next element is "measure, evaluate, and control." This is one with which the Industrial Engineer is thoroughly familiar. Indeed an important part of his working day is devoted to doing just that. As a manager, he may have to use somewhat different measurement and control techniques than he used as an Industrial Engineer and may have to apply them to many people besides the factory workers, but the principles of application are much the same. Measurements are sought which will

make it possible to evaluate how well a task or project is being accomplished. The basis for control action is provided by comparing actual accomplishment with the results that measurement has shown are attainable. Up to this point, the Industrial Engineer is right at home. It is only when it becomes necessary to take control action when performance is not up to expectations that he may find himself on unfamiliar ground. This is something customarily done by line management rather than the staff functions. Nevertheless, insofar as the element "measure, evaluate, and control" is concerned, the training provided by Industrial Engineering experience should definitely be rated as "good."

DEVELOPING PEOPLE

The next to last element of managing is called "developing people." This is one of the obligations implicit in the job of managing. The manager must get results through others. It follows, therefore, that if these others are adequately qualified through proper development, the results he will obtain will be better than would otherwise be the case. The Industrial Engineer recognizes this clearly, and in the course of his work, he endeavors through instructions, training, and coaching the foreman to see that the workers develop the skills and know-how needed to do the work properly. His efforts, however, are largely in connection with getting the workers to use the proper methods with normal skill. He is not called upon to develop the worker as a man and leader of men, but only largely as a maker of motions.

Thus once again when the Industrial Engineer turns manager he has something new to learn. As a manager, he has the responsibility implied by his very position to do what he can to insure continuity of operation. This means that he must foster the development of those who will in due time succeed him. He must encourage the development of managing skills within at least a portion of his people, and this, of course, means a good deal broader kind of development than he was accustomed to thinking of as an Industrial Engineer. Our scoring on the element of "developing people," therefore, can be no higher than "partial."

PROMOTE INNOVATION

The final element of managing is "promote innovation." This is right down the Industrial Engineer's alley. His whole training and experience is in the field of finding new and better ways of doing things. Although he seeks innovation and improvement as an Industrial Engineer largely in the activity area of production, he cultivates a deep-seated dissatisfaction with things as they are which, when he becomes a manager, he finds it natural to carry over into the other activity areas such as research and development, marketing, and finance and control. Perhaps the only important thing he will need to learn about promoting innovation as a manager, if he has not already learned it, is not to try to promote it at a rate faster than his organization can absorb it. As far as our scoring is concerned, the training provided by Industrial Engineering experience on the element "promote innovation" is definitely "good."

THE SCORE

Now, let's look at our score card. If you have accepted my scoring (and once again I readily admit that there is room for difference of opinion depending upon one's concept of the kind of work normally done by Industrial Engineers and of what the typical Industrial Engineer is like) you will note that the Industrial Engineer has a very

Elements of Managing	*Training Provided by Industrial Engr.* Good	Partial	Insufficient
1. Gather information	x		
2. Synthesize information		x	
3. Plan	x		
4. Decide			x
5. Organize	x		
6. Communicate		x	
7. Motivate		x	
8. Direct, guide, or counsel			x
9. Measure, evaluate, and control	x		
10. Develop people		x	
11. Promote innovation	x		

good start on his training for managing work. In five of the eleven elements of managing, we have rated the training provided by Industrial Engineering as good. On four others, we recognize that Industrial Engineering experience provides partial training, although the training usually needs to be broadened, particularly in the areas of human and group relations as the organization level is elevated at which these elements of managing are applied. On only two elements have we indicated that the training provided by Industrial Engineering experience is insufficient for managing purposes. These are in the areas of decision-making where the full responsibility for the results stemming from the decision rests on the shoulders of the decider and the personal leadership skills required for line work.

Some Industrial Engineers find these skills easy to acquire. Indeed they may have already partially or fully developed them either as Industrial Engineering supervisors or through previous experience in work of a line nature. Others do not acquire these skills easily and in fact may never acquire them. These are the ones who have a genuine liking for staff work, those who prefer to get results through the rational persuasion of others rather than by the exercise of direct authority. Such people may prefer to remain in Industrial Engineering work, or they may, if they have the other necessary attributes, eventually become consultants.

It should be evident from this analysis that the fact that so many Industrial Engineers are promoted into management positions is no accident. Their training and experience fits them well in many respects for this kind

of work. In addition, the Industrial Engineer usually has an exceptionally good understanding of most of the other functional areas of the business, because his work as an Industrial Engineer is such that he comes into intimate contact with them.

But Industrial Engineering experience alone does not insure success as a manager. The Industrial Engineer turned manager needs to develop additional skills to supplement those he already has, which as we have said some people find it hard to do. In addition, he needs to retain all of the pertinent skills that he developed as an Industrial Engineer. Some newly appointed managers tend to become so interested in the line aspects of their new work and in the active direction of people that they tend to become so interested in the line aspects of their of their work for which their previous training in Industrial Engineering fitted them so well. They must remember that managing is a three-step process of:

1. Establishing objectives
2. Directing the attainment of objectives
3. Measuring results

To concentrate on step 2 may be a natural tendency for an Industrial Engineer newly turned manager, but if he does, he is neglecting two-thirds of his job. He must use all of the elements of managing in balanced relationship if he is to be a success as a manager.

I. E. STILL NEEDED

One final word of caution. In demonstrating why it is that Industrial Engineers make good material for management positions, we must never lose sight of the importance of Industrial Engineering. American industry needs good managers if it is to retain its position of world supremacy. But it needs good Industrial Engineers too. So although the Industrial Engineering Department may well be used as the seedbed of management, there is an optimum rate at which transplanting and replanting should take place if the vital Industrial Engineering function is to be maintained at peak effectiveness.

The Industrial Engineering Department should never be so denuded of capable people that the quality of the work which it does is lowered. Especially in companies which are growing and expanding rapidly, it should be recognized that the element of managing called "developing people" applies to Industrial Engineers too. As management strengthens itself by drawing capable, experienced men from the Industrial Engineering Department, it must see that the Industrial Engineering replacements are in turn properly trained and instructed so that the effectiveness of the department is not gradually diluted. Inexperience can never be permitted totally to replace experience.

But this is no real problem for the manager who recognizes the problem and plans ahead. It is possible to replenish or expand the managing staff with the help of the Industrial Engineering Department and at the same time maintain the efficiency of the vitally important Industrial Engineering Department. All that is needed is a recognition of the importance of developing people at all organizational levels and the willingness to do the things that are necessary to secure this development.

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An Approach to Promoting the Applications of Statistical Techniques by the Industrial Engineer[1]

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INCREASING interest in statistical techniques for the field of Industrial Engineering is apparent from the many articles concerning these techniques which are appearing in current Industrial Engineering literature. It is probable that increased use of the tools of statistics would promote greater precision in the analysis of many problems which the Industrial Engineer encounters. There seems to be little doubt that the Industrial Engineering profession must endeavor to promote the use of statistical tools as extensively and rapidly as possible. This article will attempt to point out one approach by which adaptation of these tools may be achieved more quickly.

HIGHER MATHEMATICS

The techniques of higher mathematics have been used as tools to obtain more precise and quantitative methods in many situations. During the "maturing process," other professions went through transition periods similar to that which appears to face Industrial Engineering. It would be well to note how these professions coped with the situation of quantifying their approach to problems. As the biologists, psychologists, agriculturists, economists, and others required more precise quantitative methods of analysis, they borrowed from the disciplines of statistics and advanced mathematics. In many instances these professions adapted the techniques to their specific needs, and in the process, contributed to the advancement of the discipline from which they borrowed. As an example one might cite R. A. Fisher's factorial design of experimentation in agricultural research. It seems that Industrial Engineers, who have a thorough background in basic mathematics, might gain by emulating these "older" professions.

There are publications within these "older" professional groups which the Industrial Engineer might find useful. This literature contains many articles discussing and explaining specific applications of mathematical methods to various kinds of problems. Of course, the usual problems are those of interest to the profession in which the publication is most widely circulated.

The Industrial Engineer would have to study these articles not only from the standpoint of the method of applying the mathematical tool, but also from the standpoint of comparing the characteristics of the problems attacked with the problems he is encountering. He would have to translate the variables and problems discussed into Industrial Engineering variables and problems which have analogous characteristics. That is, it would be necessary for the Industrial Engineer to make a transition from the psychological, economic, or other problem discussed to a problem of cost reduction, plant layout, machine choice, etc. Once the transition was made, though, several new ideas for methods of approaching problems in management and Industrial Engineering with precise analytical tools might become apparent.

STATISTICAL PROCEDURES

Many authors of articles in these publications explain statistical procedures in nonmathematical language. This point is made by Mosteller (3) in the opening paragraph of the Statistical Theory and Research Design section of the 1953 *Annual Review of Psychology*. He states:

> During 1951 and 1952 there has been a continuation of the trend to present in nonmathematical language statistical material not so long ago available only to readers willing and able to cope with strong doses of mathematics. These expository articles state the assumptions underlying the statistical models they discuss, and sometimes offer alternative procedures with differing assumptions for solving the same problem. Some articles present examples worked in detail so readers are supplied with a program for computation.

This work provides a summary of much of the work done in 1951 and 1952 along the lines expressed in the

[1] A portion of the material for this article was obtained by the author while working for the degree of Doctor of Philosophy, in the Department of Industrial and Management Engineering in the Graduate College of the State University of Iowa under the guidance of Professor J. Wayne Deegan (2).

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above quotation. That many areas of statistical procedures are covered is indicated by the sub-topics of this section, which are: Test Methods, Selection Procedures, Nonparametric Statistics, Ranking Methods, Contingency Tables, Regression, Quick Methods, Effects on Some Common Statistics of Departures from Assumptions, Suggestions for Models or Transformations, Surveys, and Scaling. It seems apparent that the Industrial Engineer might find publications such as this of considerable aid, especially in statistical methods, in approaching many of his problems.

In giving consideration to publications of other disciplines, mention should be made of the writings with respect to mathematical procedures in the technical journals[3] of the mathematics profession. Of course, in these publications, the case study approach or explanation of the application of mathematical methods to problems of Industrial Engineering and management are minimal. The general approach is of a technical nature in the explanation of the theory of new mathematical procedures. These publications, therefore, would have the greatest meaning and be of the most help only to those individuals who have a good foundation in theoretical statistics and mathematics. The individual will have to make the transition from theory to practical application himself, and for those Industrial Engineers who could perform this function these publications would be of considerable value.

An article titled "The Constant-Sum Method Applied to Scaling Subjective Dimensions" (1) appeared in *The American Journal of Psychology*. This article will be used to illustrate how methods of other disciplines might be applied by the Industrial Engineer.

The summary of the article was:

The constant-sum method was employed to obtain scales for subjective dimensions represented by "roughness" of sandpapers and "preference" for neckties. With respect to roughness it was found that Os (observers) agreed with themselves and with each other at least on the rank-order of stimuli, and a number of specific relationships within the sets of scale-values were common to all Os. For the preference-dimensions, there was a fair degree of agreement between scales determined for different groups and between scales determined for the same group on two occasions. There were, however, sex-differences with respect to the placement of items on this dimension. It was concluded that consistencies in scale-values indicated measurement on scales that reflected more than merely the ordinal characteristics of items, although the requirements of a true ratio-scale may not have been met fully. The implications of these results were discussed and various problems arising in attempting to determine the characteristics of scales determined for subjective dimensions were considered.

[3] These include such publications as: *The Journal of the American Statistician, The Annuals of Mathematical Statistics, The Royal Statistical Society Journal, Mathematics Magazine, Applied Statistics, The American Mathematical Monthly, The American Statistical Association Journal,* and *The Journal of Mathematics and Physics.*

PRODUCTION SCALES

To make a transition of this discussion to a problem in Industrial Engineering, one must visualize in what way "scales for subjective dimensions represented by 'roughness' of sandpapers and 'preference' for neckties" suggest areas of application. Consider first the term "subjective dimensions." Many Industrial Engineering predictions are based on estimates or trends, for example, predicted production figures used in production control. Usually these figures are based on expected sales and/or historical data as they are assumed to predict consumer demands. Measures such as predicted production figures are analogous to "subjective dimensions" for the psychologist. Next, consider the term "scales for." It would be very helpful for the Industrial Engineer to have a measuring "scale" for his predictions, such as predicted production figures or expected sales which would permit more objectivity in the production control techniques. Just as the psychologist is interested in "scales for subjective dimensions," the Industrial Engineer is interested in scales for predicted production figures. Last, consider the phrase "represented by—'preference' for neckties" or any other product. Predicted production figures or expected sales reflect to a great degree the "preference" of the consumer for the various products manufactured by the plant.

Thus it follows, if "subjective dimensions" can be measured it would be well for the Industrial Engineer to base predictions on this type of "measuring scale."

Now that the transition of terms has been given consideration and some applications seem apparent, it would be well to consider the technique in detail. For purposes here, consideration will be given only the "'preference' for neckties" experiment as follows: (1)

Method. The Os were volunteers from undergraduate psychology courses. To investigate possible sex-differences in preference, and to have some Os give ratings on two occasions, three independently constituted groups were employed: Group A, 29 men who rated the stimuli only once; Group B, 19 men who judged the stimuli in two sessions a month apart, hereafter designated as B_1 and B_2; and Group C, 29 women who judged the material only once.

The stimulus-objects judged were eight equal-sized, printed, color-productions of neckties. To control color as a variable, the samples were predominantly blue. There were 28 possible pairings of the 8 ties, and the order of presentation for judging was random except for the restriction that no tie appeared in successive pairs. Each pair was shown on a large screen by means of an opaque projector. The Os were instructed to divide 100 points between the members of each pair so as to indicate their relative degree of "liking" for the two ties. These judgments were made following a series of 20 judgments of line-lengths, which provided some experiences in making judgments in terms of point-divisions.

Results. Procedures used to compute scale values were the same as in Experiment I. Scale-values of the neckties as determined for the various groups are shown in Fig. 2.

It is apparent from Fig. 2 that the two groups of men agree quite closely with respect to the order of stimuli. One index of this agreement is *tau*, a coefficient of agreement based on the number of interchanges necessary to make two sets of orders

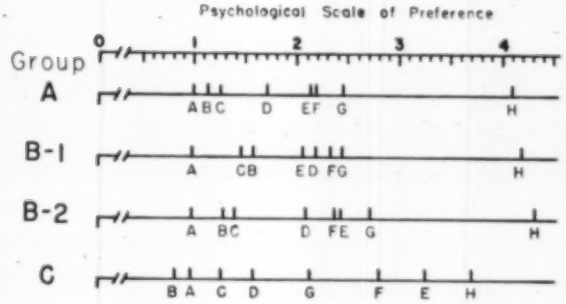

FIG. 2. Scale-Values of Eight Neckties as Determined for Three Groups of Judges.

correspond. With two interchanges the order of items for Group A corresponds to the order for Group B_1 ($\tau = 0.86$) and only one interchange results in orders identical for Group A with those from Group B_2 ($\tau = 0.93$). Three interchanges are required to make orders for Group B_1 and B_2 comparable ($\tau = 0.79$). Thus it appears that two independent groups of judges agree as well as do two judgments made by the same group on separate occasions. A mere count of interchanges does not reflect certain important uniformities manifested in the sets of scale-values for the groups of men.

Analogous with the roughness judgments, rather striking consistencies with respect to the relative distances maintained between stimulus-objects are evident from group to group.

In general, the agreement between orders for women and men is somewhat poorer. The 4, 6, and 3 interchanges required to bring about corresponding orders yield τs of 0.71, 0.57, and 0.79, respectively. Although all coefficients are significant, sex-differences with respect to preference for the neckties are suggested.

Although this technique is still in an exploratory phase, as indicated in the summary of the article, it does present an approach to the solution of a problem which would seem to have relevance in production planning. It would provide a method for obtaining certain kinds of information which would be of practical value. Even though the psychologist views the technique of using these subjective measures as a "methodological issue" since ". . . the requirements of a true ratio-scale may not have been met fully" (1), the Industrial Engineer could transform this technique into a useful method for solving some of the immediate problems with which he is faced. For example, the technique might be applied in production control, to make more precise or more reliable estimates of predicted production figures for various products.

Use of the "Psychological Scale of Preference" and the predicted preference of "Group A" (Figure 2 in the quoted material) will be used here to exemplify the possible application of this technique to production control. It will be assumed that the sales department or the market research department will provide the production control department with the predicted total sales for the forthcoming period, for example, 10,000 gallons of ice cream in the coming month. The production control department knows the various competing flavors of ice cream that must be produced and might schedule production of the various flavors based on past sales of each type. Consider the possibility that scale values for the preference of the competing flavors are available, obtained by the method described in the necktie experiment cited, say (from Scale A, Figure 2) flavor $A = 1.00$, $B = 1.13$, $C = 1.24$, $D = 1.70$, $E = 2.14$, $F = 2.19$, $G = 2.43$, and flavor $H = 4.10$. Now the prediction would be that output should be geared in these ratios so that the items will be produced in proportion to their expected sales. The formula:

$$P_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \times TS$$

Where:

P_i = The production output of item i.

S_i = The scale value of item i.

$i = 1, 2, 3, \cdots, n$ or in the case cited $A, B, C \cdots, H$.

TS = Total sales

can be used to convert predicted total sales into production output figures for each of the various items. In this case, the production of flavor A would be 630 gallons, flavor $B = 710$, $C = 780$, $D = 1{,}070$, $E = 1{,}314$, $F = 1{,}370$, $G = 1{,}520$, and production of flavor H would be 2,580 gallons. Thus, knowing total sales, production figures for all products can be predicted provided that the sales of the items follow the measured preferences for the items. Now suppose a new product is added to the production schedule. There are no past sales upon which predicted production figures can be based, but a preference scale value for this new item can be obtained. So, with use of the foregoing formula the predicted production figure for this new product can be established.

There are obvious complications which can be encountered with this technique. These could arise if the sales and thus the production of the products are dependent on many variables or features, i.e., a group of products where price, design, color and size vary for each product and can affect preference. All of these variables would have to be considered as part of the stimuli affecting consumer buying habits. These considerations do complicate the picture but do not represent any real limitations so far as method is concerned.

There may be certain situations to which the technique described above would be directly applicable after a short test period. However, it is more likely that the application of this technique of scaling would require modification and extensive validation before the Industrial Engineer could include it in his kit of tools for production control. This example does not represent a tried and true technique for production control. The author has cited this case in an attempt to show how the terms of an

apparently unrelated discipline (in this instance psychology) can be translated into Industrial Engineering terms and therefore possibly be of help to the Industrial Engineer.

Many techniques that are described in the publications of other disciplines might be "adapted" to similar problems as they are encountered in Industrial Engineering. In the majority of the cases the technique cannot be just borrowed and applied, but it might be made to fit the Industrial Engineering problem. It may be a more reliable or better method than the one that the Industrial Engineer uses at present. Becoming familiar with techniques of other disciplines also will give the Industrial Engineer a new or different approach to the problem, and in this way possibly suggest a more refined or more valid method for attacking management problems. The Industrial Engineer may also contribute to the advancement of statistics and mathematics through the development and application of new approaches to management problems.

SUMMARY

Consideration has been given an approach to promoting the application of statistical techniques by the Industrial Engineer. This approach is that of borrowing from some of the "older" professions which have adapted the techniques and contributed to the advancement of the disciplines of statistics and mathematics, for example: agriculturists, biologists, economists, psychologists. A case was cited indicating the necessary translation of terms from the "foreign" discipline to the terms of Industrial Engineering. It seems apparent that the Industrial Engineer could make considerable use of statistical applications in other disciplines by visualizing and translating the variables and problems of these cases into Industrial Engineering terms.

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Safety Performance Measurement

by **THOMAS H. ROCKWELL**

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ONE of the frustrations that has plagued those who labor in the field of accident prevention has been the problem of the measurement of safety performance. Safety practitioners and researchers alike are forced to measure the effectiveness of their work by vague, invalid and insensitive criteria such as lost time accidents, accident frequency rates or first aid cases. The use of such poor measures of effectiveness complicates an already overly complex problem area which involves many misinterpreted, ill defined and unquantitative terms such as accident proneness, safety morale, job hazard, safe attitude, unsafe act, fatigue and safety motivation. The problem of criterion measurement is certainly not unique to the safety field. Measurement is an absolute prerequisite to control whether this be the control of production or accidents. Accurate measurement teamed with proper control provides prediction of future performance. Present attempts to control accidents and their consequences can be well described as trial and error chiefly because adequate measures of the effectiveness of this control do not exist.

The safety engineer or supervisor in formulating an accident prevention program is continually confronted with this problem. Inspections, training programs, safety contests, etc., are initiated under various levels of effort and evaluated by the only measures available, namely, lost time accidents, first aid frequency or accident costs. Because lost time accidents are rare events (especially when interpreted under ASA Z16.1-1954) and first aid cases are subject to serious reporting inaccuracies, the safety director is faced with only an intuitive notion of the effectiveness of various accident prevention methods. The researcher in this field faces the same criterion problem. The inability to reproduce the accident phenomenon in the laboratory forces him to make use of criteria which are hopefully related to accidents, such as operator error (as operationally defined). Despite the fact that measurement is so critical in accident control,

the majority of efforts in accident prevention have been concerned with techniques of control, such as guard design, training, etc. Little research has been devoted to the problem of how to evaluate the effectiveness of these control techniques.

CHARACTERISTICS OF AN IDEAL SAFETY PERFORMANCE MEASURE

One approach to this problem would be to consider some of the characteristics of a good criterion of safety performance. Of prime importance is the necessity for a criterion to be quantifiable. Qualitative evaluation of safety performance prohibits statistical inference and opens the way for individual interpretation. The ideal criterion(a) of safety performance should permit statistical inferential procedures, because like most other measurable quantities dealing with human behavior, safety performance will necessarily be subject to statistical variation. The criterion should also be valid or representative of what is to be measured. Does safety involve the minimization of disabling injuries and first aid cases or the minimization of all consequences of unsafe behavior and unsafe conditions? Near accidents or no injury accidents constitute a dilemma in this regard since their occurrence may result in a cost to the company and signal future disabling injuries. Moreover, the effect of unsafe behavior on production efficiency in the absence of property damage or injury may constitute a considerable cost to the organization and yet go on unmeasured. Despite the fact there is no injury or property damage, unsafe behavior of itself requires the attention of the safety supervisor. The oft-used accident frequency rate is thus a poor indicator of safety performance since it fails to take into account other associated consequences of unsafe behavior and unsafe conditions. A third characteristic of an ideal measure of safety performance is that it should be reliable to the extent that it provides minimum variability when measuring the same condition. The repeatability of a measure is related to the accuracy or precision of the measurement itself. In safety this involves the notion of reporting. First aid frequency has always had dubious reliability since under identical situations some workers will report for first aid while others will self-administer minor injuries. Associated with reliability is the need for a criterion to be stable. This involves the maintenance of a given range of values under repeated measure of worker behavior and environmental conditions. An ideal measure of safety performance must also be sensitive to changes in environmental or behavioral conditions. This characteristic of a good criterion is significantly lacking in present-day safety measurement. Since lost time accidents are rare events, the initiation of a training program, for example, may not be reflected in reduced accident frequency rates. With insensitive measures of safety performance, the proper evaluation of accident prevention methods becomes extremely difficult. Finally, a criterion should be both efficient and understandable. Efficiency requires that the cost of obtaining and using the measurement is consistent with the benefit to be gained. Near accident measurement is a good instance of a criterion which requires excessive cost to obtain and verify. To be understandable suggests that the criterion be of such nature that it can be comprehended by those charged with the responsibility of using or approving it. Statistical measures are often confusing to the uninitiated, and terms such as emotional instability, neurotic, etc., in addition to possessing inherent problems of quantification, have little meaning to the average manager.

These characteristics of a good criterion briefly outlined above are rarely achieved in any one measure. Sometimes a combination of measures can provide a reasonable compromise. The fact remains, however, that in the field of accident prevention, presently used measures of safety performance are inadequate in many of the characteristics cited. The criterion described below possesses many desirable criterion characteristics, particularly when viewed as a measuring instrument for research in safety problems.

UNSAFE BEHAVIOR AS A PERFORMANCE CRITERION

Since the initiation of the safety movement after the turn of the century, more and more emphasis has been directed to the control of behavioral rather than environmental conditions which contribute to accidents. Alert safety departments armed with modern engineering methods and backed by state safety codes have eliminated the hazardous workshops which were born with the sudden industrialization of our economy. Studies overwhelmingly point to the dominant role of unsafe behavior in accidents today. Heinrich's 88:10 ratio of personal to environmental causes of accidents while overgeneralizing the situation, at least is indicative of the belief of accident preventionists (1). Moreover, it is unfortunately true that despite efforts to safeguard equipment, workers often have little trouble removing this protection and subjecting themselves to injury. A glance at the efforts of safety practitioners shows that the principal share of time and dollar expenditures is directed at methods of promoting safe behavior. This does not suggest that unsafe conditions are nonexistent, but that the greatest gain in accident reduction lies in the elimination of unsafe behavior.

Viewed in another light, the initiation of such accident prevention methods as training programs, safety contests, propaganda, inspections, safety committees, etc., is principally designed to modify behavior and indirectly to reduce accidents. The difficulty suggested by this analysis is the problem of how this behavior is measured. One method of measuring this behavior is to operationally define what constitutes unsafe behavior and measure the extent of its occurrence. Research has recently been con-

ducted using activity sampling methods to estimate the extent of this unsafe behavior on a plant-wide basis (3). This procedure has several advantages: A. it enables the collection of a large sample of behavior in a minimum of time; B. it permits the calculation of sampling error; C. taken without operator cognizance, it provides a valid indicator of safety behavior.

The procedure essentially consists of an observer taking instantaneous random observations in time and noting whether the worker is engaged in safe or unsafe behavior. All worker behavior is thus dichotomized as safe or unsafe. Unsafe behavior involves known violations of safety regulations or behavior which can be reasonably construed to be unsafe in consideration of existing environmental conditions. Usually the plant safety engineer and department foreman can list those instances of operator behavior which, for the particular job under study, have been known to result in first aid or lost time accidents, since the unsafe act is normally included in accident and first aid reporting. It should be noted also that the procedure necessarily requires that the behavior be observable, e.g., it would be extremely difficult to use this method of measurement on operators working in concealed spaces.

AN APPLICATION OF THE METHOD

A recent application of this method (2) was made to eight assemblers in a large aircraft manufacturing plant.[1] The eight workers included six men and two women, all of whom had been employed in this type of work for four years. Moreover, all had worked for the company for at least six years and had been equally exposed to plant safety regulations during this period. The purpose of the study was to evaluate this procedure as a criterion of safety performance in terms of its practicality, stability, sensitivity and relationship to other currently used safety criteria. The determination of an unsafe act on this job was stipulated by the chief safety engineer and consisted principally of violations of company safety regulations and behavior specifically prohibited in this work. Each worker carried the same job description and performed the same tasks. The opportunity for commission of unsafe acts was assumed equal for every period in time since the work cycle was begun at all times throughout the day. These unsafe acts included the following:

1. Working with loose tools underfoot.
2. Working without goggles when required.
3. Working under suspended loads.
4. Failure to use guards as provided.
5. Working in unsafe postures.
6. Wearing improper or loose clothing.
7. Use of shock tools with mushroomed heads.
8. Improvising unsafe ladders and platforms.
9. Running.
10. Misuse of air hose.

[1] The author is indebted to the Safety Department of North American Aviation, Inc., Columbus Division, for their generous cooperation in this study.

The observer was instructed to take random samples (in time) of the eight operators from a catwalk above the job site. The workers were not aware of the study. In fact, in order to insure unbiased results, the department foreman was not informed of the survey until its completion. Twenty observations of each operator were made for 17 work days. The results of the study are shown in Table 1. For each operator the daily proportion of unsafe behavior was recorded. Those days in which an operator was absent are indicated by the letter "A" followed by the average reading for that worker for the entire study.

DATA ANALYSIS

The data was first analyzed by conventional quality control chart methods. Figure 1 shows the group data plotted over the 17 days of the study. The data can be viewed as consisting of four distinct periods. The first period is one of stable performance; all values lie within 2 sigma limits of the average proportion of .175. The second period consists of the 3 days following the first safety inspection on the 8th day. The average proportion of unsafe acts here is .10. The third period shows the return of the group behavior to the original average proportion. The fourth period consists of the four days following the second inspection on the 14th day.

The effect of inspections on safety behavior is most striking when viewed in control chart terms. The inspection on the morning of the 8th day dropped the proportion of unsafe acts from .21 to .06 and after 3 days the proportion returned to its previous level. This inspection was part of normal plant practice. Each month the safety department made an unannounced inspection of each operating department. It was decided to coincide this inspection with the safety study to evaluate the effect of inspections on operator safety behavior. During the inspection, which took about 2 hours, both unsafe acts and unsafe conditions were checked. The assembly depart-

TABLE 1.

Per Cent of Unsafe Behavior Observed for 8 Aircraft Assemblers

	Workers							
Day	1	2	3	4	5	6	7	8
1	16.6	35.2	31.5	00.0	21.0	16.6	5.0	21.0
2	15.8	A-25.4	33.3	5.2	20.0	5.2	10.5	27.8
3	00.0	27.8	27.8	11.1	26.3	00.0	10.0	25.0
4	29.4	33.3	47.3	00.0	22.2	15.8	5.5	21.0
5	33.3	27.8	21.0	5.2	10.5	22.2	00.0	5.5
6	36.8	29.4	20.0	5.0	21.0	5.5	00.0	10.5
7	21.0	38.8	10.5	10.5	10.5	15.8	15.0	45.0
8	00.0	11.8	15.8	00.0	5.0	00.0	00.0	16.6
9	15.8	5.9	5.9	5.5	15.8	5.0	22.2	15.8
10	10.5	20.0	5.5	5.0	15.8	00.0	5.2	22.2
11	21.0	47.0	22.2	0.0	25.0	00.0	00.0	5.9
12	15.8	25.0	42.0	5.2	16.6	00.0	15.8	26.3
13	26.3	20.0	11.8	00.0	A-14.4	11.1	15.0	33.3
14	15.8	21.0	11.1	00.0	10.5	00.0	A- 7.8	21.0
15	5.5	11.8	00.0	5.2	00.0	5.2	A- 7.8	25.0
16	11.1	10.5	00.0	00.0	00.0	5.2	A- 7.8	36.8
17	A-12.1	25.0	15.8	10.5	20.0	11.1	10.5	22.2

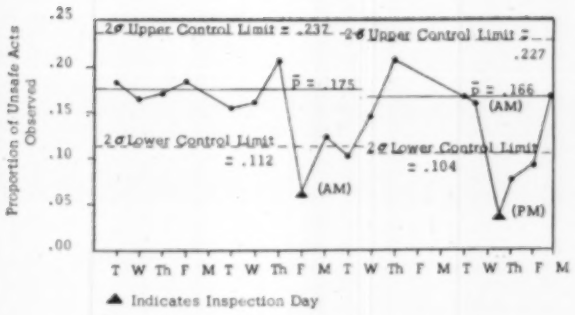

FIG. 1. Group Control Chart for Proportion of Unsafe Acts (Wing Fabrication).

ment received a high rating at this inspection. At the request of the chief safety engineer a second inspection was made to evaluate the effect of consecutive inspections on the group. Although a second inspection was not usually made so soon after a previous inspection, it still had a sharp influence on safety behavior. The proportion of unsafe acts dropped from .165 that morning to .04 that afternoon and returned to normal after three days.

Further analysis of the data by analysis of variance methods showed that there was a significant difference at a .17 significance level between the mean performance of the individual operators. This same result was demonstrated with the data classified for all 17 days and for the 11 days of stable group performance (inspection effect removed).

With data cross classified by operator and all 17 days, the mean performance of the individual days was significant at the 5% level. With the inspection effect removed (i.e., days 8, 9, 10 and 14, 15, 16) there was no significant difference in day performance at the 20% level. This supports the division of the total data into the four periods as shown in the control chart analysis. The difference in individual operator performance is also verified by inspection of Table 1 and the control chart analysis of Figure 2 where the behavior of two operators is shown. Worker No. 2 has the highest over-all average proportion and worker No. 4 has the lowest average per cent of unsafe behavior.

The data were also analyzed to determine the relationship between safety behavior and other indices of performance. The first question was whether one could predict lost time accidents or first aid frequency from knowledge of unsafe behavior. In examining the safety record of the eight assemblers it was found that none had ever had a lost time accident. Using first aid frequency it was found that the top three of the eight workers in terms of unsafe acts accounted for 60 percent of the total first aid cases of the group. The use of rank correlation methods, however, yielded a coefficient of only +.245 when workers were ranked in terms of first aid cases and percent unsafe acts. The size of the sample of workers prohibits any conclusion about this analysis. However, there does appear to be some relationship which would warrant further investigation.

One question which is of extreme importance in using unsafe acts as a measure of safefty performance is whether there is a relationship between production efficiency and percent unsafe acts. In the plant studied, no record of individual employee output was maintained, so no direct comparison was possible. After the study the foreman and assistant foreman were asked to rank the workers according to their productivity. Their combined rankings were compared to the ranking of the workers with respect to average percent unsafe acts. The resulting rank correlation coefficient was +.571. Despite limitations in sample size the data strongly suggest that for this particular department some risks may be required for workers to be maximally productive. This result is in sharp contradistinction to plant studies that positively relate safety and production efficiency (4).

A third analysis of the data was made to relate the occurrence of unsafe acts and time off the job (not absenteeism). The latter was available from the work sampling data. The workers were again ranked with respect to time off the job and average percent unsafe acts. The resulting rank correlation coefficient was +.552 which shows some positive relationship within the limits of the sample size. Further study might indicate whether time off the job and unsafe behavior are directly related or merely manifestations of some personal characteristics of the operator.

SUMMARY

The stability and sensitivity of this measure as demonstrated in Figure 1 in this study offers several interesting possibilities. The observed relationship between the proportion of unsafe acts and first aid frequency suggests that this measure may be used to predict lost time accidents and first aid cases *before* their occurrence. The small sample used in this study, however, prohibits any generalizations at this point. The prospect of relating productivity and unsafe behavior certainly seems to warrant

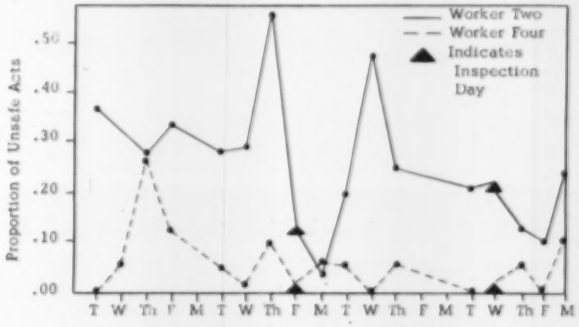

FIG. 2. Individual Control Chart for Proportion of Unsafe Acts (Wing Fabrication).

further study. It may well be that a positive relationship exists here that has been overlooked by safety practitioners. The consequences of unsafe behavior may not just be lost time accident and first aid costs, but may involve a decrease in production efficiency and the cost associated with this inefficiency. Past research on the relation between safety and production efficiency has been on a plant-wide basis (4). Such studies have simply shown that safe and efficient plants are compatible. This fact, however, has little significance because so many other factors are involved. An enlightened management is likely to be both safety conscious and efficient in production. With the suggested criterion of safety performance it would be possible to test this relationship on an *individual operator basis.*

Other research possibilities include the measurement of the effect of nearby accidents, safety training, supervision, propaganda methods, placement, and safety contests on operator unsafe behavior. Moreover, attitude tests could be given to workers to see if favorable attitudes toward safety are reflected in safe behavior. If the effect of inspections on behavior can be measured as indicated in the reported study, then this might suggest the optimum allocation of inspection activity to various departments to obtain maximum results. In addition, it could provide the safety supervisor with information as to how often a department should be inspected to maintain the best results in terms of safe behavior. If the results of this study are at all indicative, it would be possible to objectively test many of the assumed relationships in the field of safety, such as the effect of age on safe behavior. Ultimately, it might be possible to provide psychological tests which would correlate with unsafe behavior and permit better screening and placement at the time of employment. This suggested measure of safety performance offers a new approach to the much debated "accident prone concept." Personal accident susceptibility would be measured in terms of personal exposure to accidents, i.e., unsafe behavior, instead of lost time accidents and first aid cases, with their associated reporting and causal complications.

Since this study was conducted over a short period of time and limited to a small sample of workers, no claim can be held that a breakthrough in the measurement problem in safety has been made. Many of the necessary conditions underlying this method are difficult to achieve in practice, such as independence between observations, the ability to dichotomize behavior as safe or unsafe, equal exposure to environmental hazards and equal opportunity for risk taking behavior. Furthermore, no attempt to scale the seriousness of the unsafe acts committed has been attempted. Yet, the results of the reported study are encouraging and strongly suggest that further effort be devoted to this line of research. Certainly the magnitude of the accident problem today warrants intensive investigation. We cannot afford to be contented with our present lack of knowledge of this problem. The heavy loss of life and limb due to accidents in this country and the billions of dollars involved demand that every avenue of possible benefit be explored.

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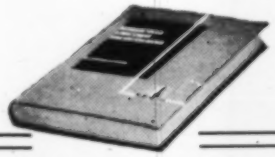

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Statistical Scheduling of a Highly Mechanized Production Facility*

by WILLIAM F. POUNDS and ERWIN P. KRAAI

Industrial Engineering Division, Eastman Kodak Company

TRADITIONALLY, the scheduling of production has really been the scheduling of time. It has been assumed that production is a direct result of scheduled working hours. This assumption has been valid for practical purposes on all hand or semi-mechanized operations. As production facilities have become more highly mechanized, however, a situation arises where production is not only a result of working hours but also of machine performance during those hours. The introduction of this additional factor makes time scheduling alone inadequate. Production scheduling must now be based on machine performance as well as time.

For a given level of production, the higher the degree of mechanization the fewer producing units required. Let us compare some operating characteristics of two systems of different degrees of mechanization.

OPERATING CHARACTERISTICS

Let us assume our goal is 1000 units per day. System A has a low degree of mechanization and requires 100 machines at 10 units per machine per day. System B, a highly mechanized system, requires one machine at 1000 units per machine per day.

Let us assume that the relative variability of both types of machines is the same, $\pm 50\%$ of the mean 95% of the time. Because System A is made up of 100 machines its total system variability is only 1/10 the variability of System B. System A will produce 1000 ± 50 (950 to 1050) units per day. System B will produce 1000 ± 500 (500 to 1500) units per day.

Although both systems produce the same on the average, the system with higher mechanization has greater daily variability.

This simple example indicates why scheduling with a large number of low volume units is primarily a matter of scheduling time. High mechanization, however, has introduced more variability and thereby introduced new scheduling problems. Scheduling time alone could cause us to miss our goal a good share of the time.

Now let us explore in more detail some of the factors involved in scheduling from more highly mechanized production systems.

SCHEDULING MECHANIZED SYSTEMS

Figure 1 shows some typical production data from a highly mechanized production facility. The points on the chart represent total production obtained from this machine during a series of days on which two-shift operation was scheduled. Production varies approximately $\pm 50\%$ of the mean from the mean 95% of the time.

There are two reasons for this high variation. The first reason is a relatively large amount of unpredictable downtime due to the extreme complexity of the electronic and mechanical components of the machine. Even though each component by itself may be very reliable by ordinary standards, the combination of many such components rapidly reduces the reliability of the over-all machine. For example, if a machine is made up of 100 components each of which is 99% reliable, the reliability of the machine, as a whole, will be only 35.5%. The second reason for the high production variability is the fact that there is only one machine turning out product. Before mechanization, total output was the sum of the production from a number of producing units. Thus the central limit theorem effect tended to mask even high

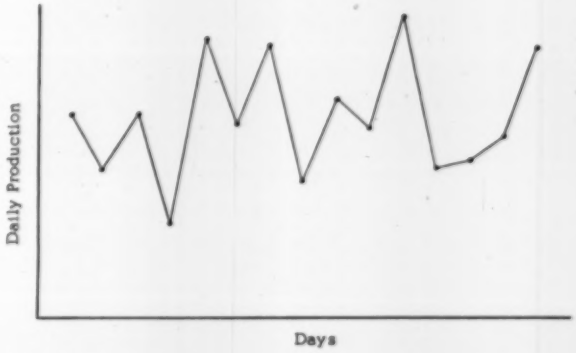

FIG. 1. Typical Production Data from a Highly Mechanized Production Facility.

* The writers wish to acknowledge the assistance both in the project and in this presentation of James A. Richardson, Senior Engineer, and John M. Allderige, Technical Advisor, Industrial Engineering Division, Eastman Kodak Company.

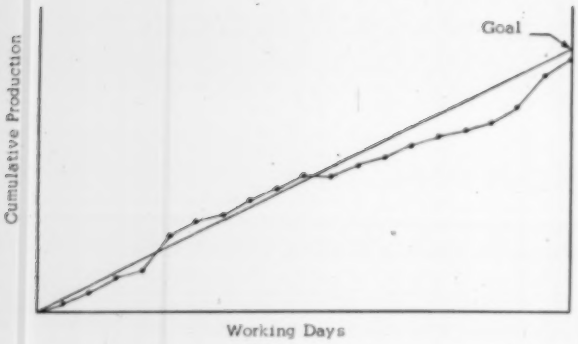

FIG. 2. Traditional Manner of Scheduling Production.

variation of the individual units to the extent that total relative variation was quite small. As the number of producing units decreases, however, the over-all variability of the productive system increases and finally approaches the variability of an individual unit when only one production unit is involved. Notwithstanding these reasons for variability, the problem remains one of scheduling production of this type to effectively meet rigid monthly requirements.

It is interesting to note that for a time, production from this machine was scheduled in the traditional manner as shown in Figure 2. A chart was constructed with units of production plotted on the ordinate and working days in the month plotted on the abscissa. The production required for the coming month was plotted on the last working day, and a straight line drawn from this point to the origin constituted the schedule. As the month passed, total production to date was plotted at the conclusion of each working day.

Thus points plotted above the schedule line indicated that total production to date was ahead of schedule and points below this line indicated a behind schedule situation. This position relative to the schedule line was a major criterion of future production planning although consideration of in-process inventories and subsequent production operations were also involved in this decision. Note, however, that this method is basically one of looking backward—counting past production, then adjusting the production rate so that future production counts may be closer to the schedule. Now certainly there is nothing wrong with this method of scheduling. It is widely used and in fact, had been used successfully for years before mechanization in the situation here described.

With the coming of mechanization, however, two things changed. First, slight changes in production rates are no longer possible. This machine either produces at full capacity or not at all, and since operation of it for less than a complete 8 hour shift is not desirable from an operational point of view, basically, there are only three production alternatives each day, i.e. one, two or three shift operation.

Second, even if current total cumulative production is "on schedule" or on the straight schedule line this does not mean the eventual production goal will be met. Machine performance can deteriorate to such an extent toward the end of the production period that the goal will be missed.

What is needed, then, are new criteria, ones that take into account possible future performances as well as past production and which will indicate feasible future schedules in terms of whole shifts.

ESTABLISHING CRITERIA

The use of elementary statistics in the analysis of past production data yielded these criteria in the form of a chart (Figure 3). This chart has the same units on its axis as the chart previously used, i.e., cumulative production versus working days in the month. Instead of a single straight line, however, this chart has two curved lines drawn on it at the beginning of each month based on calculations as follows.

The upper line is called the two-shift safe operating limit line and the lower one is the three-shift safe operating limit line. These lines divide the chart into three areas, each with a different implication as far as scheduling is concerned. Certainly a one-shift safe operating limit line exists and could have been calculated by the methods outlined here. In the situation described in this paper one shift per day was not normally scheduled.

If the plotted point of cumulative production falls in the area above the two shift limit line, a two shift schedule will assure meeting the production requirements by the end of the month. If the point falls between the two limit lines, a two-shift schedule *may* yield the required production, but a shift to a three-shift schedule will assure it. However, if the point falls in the area below the three-shift limit, a schedule of three shifts for the remaining working days will not assure the required production.

By using this chart it is possible to evaluate the current cumulative production in relation to the goal and determine the shift level necessary for the remainder of

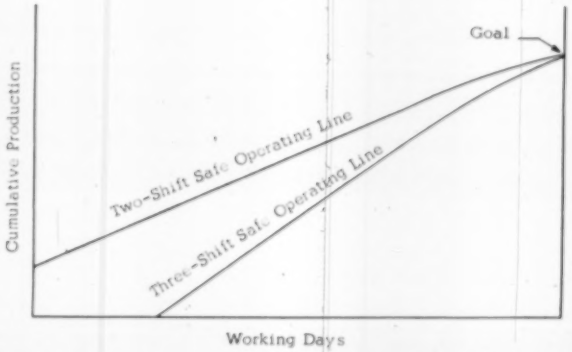

FIG. 3. Scheduling Chart with Statistical Decision Limit Lines.

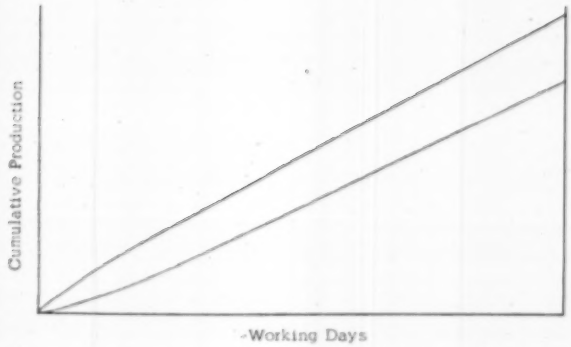

FIG. 4. Scheduling Chart with Two-Shift, Two Sigma Limit Lines.

the producing period. The chart also permits anticipation of the need to change shift levels if production shows a trend toward an action limit. It is, therefore, doubly valuable.

This chart can also be used to predict the result of producing for any length of time at a given number of shifts per day. This can be extremely valuable in predicting when to change the number of operating shifts per day, a change which is inconvenient to the personnel involved and disrupting to following operations and inventories.

The calculation of the operating limit lines follows from one basic statistical law, i.e., that the variance of the sum of two variables from independent distributions is equal to the sum of the variances of the two distributions. The mean and the standard deviation of the data illustrated in Figure 1 were calculated. Traditional tests were made to determine if the data were in control. These parameters yielded an estimate of the average production to be expected from a two-shift working day and the possible variations from this average. A normal distribution of daily production will be assumed for ease of explanation. However, the Camp-Meidel or Tchebycheff's Inequality can be used in situations where the assumption of normality is not valid.

CONFIDENCE LEVEL

The selection of a confidence level has interesting ramifications as will be noted later. In this case, however, failure to meet the required production level on time is felt to be quite serious and so a 2½% chance of failure is considered acceptable. Two sigma limits about the mean will approximately yield this protection against under-production. Thus the average plus and minus two sigma defines the limits of production which can be expected from one two-shift day. This may be expressed functionally as follows:

$$P_2 = a_2 \pm 2\sigma_2 \qquad \text{Eq. 1.}$$

P_2 = Production to be expected from two-shift schedule

a_2 = Average daily two-shift production

σ_2 = Standard deviation of daily two-shift production

Of course this function has limited usefulness since it will only predict production from one day to the next. Its usefulness can be extended, however, by writing it as the sum of N such days as follows:

$$P_2 = a_2 N \pm 2\sigma_2 \sqrt{N} \qquad \text{Eq. 2.}$$

N = Number of working days

This function characterizes two-shift production and is shown graphically in Figure 4. The area between the two limit lines will contain 95% of the points generated by a continuous two-shift schedule.

Thus from any level of production on any day of the month, it is possible to foresee the consequences of such a schedule. Figure 5 shows a daily plot of cumulative production to a point 9 days from the end of the schedule, when total production equals X.

The points Y and Z can be determined by use of an overlay of the information presented in Figure 4. If this overlay were superimposed on Figure 5 with the origin at point X, the limit lines would pass through points Y and Z as shown in Figure 6. If the lower of these two values (Y) is equal to or greater than the required production for the month, then it is safe (2½% risk or less) to operate on a two-shift basis for the remaining 9 days.

This use of the overlay can be further simplified by calculating algebraically the equation of a curve such that, if the origin of the overlay (Figure 4) were placed anywhere on it, the lower limit line would pass through the production goal. This curve is shown graphically in Figure 7 and its equation is as follows:

$$S_2 = G + 2\sigma_2\sqrt{M - N} - a_2 (M - N) \quad S_2 \leq G \qquad \text{Eq. 3.}$$

$$S_2 = G \qquad S_2 > G$$

N = Number of days worked in the scheduling period

M = Total number of working days in the scheduling period

G = Production goal in units

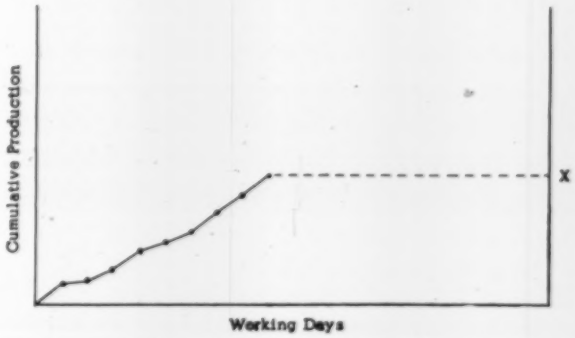

FIG. 5. Record of Cumulative Production to Nine Days before the End of the Production Period.

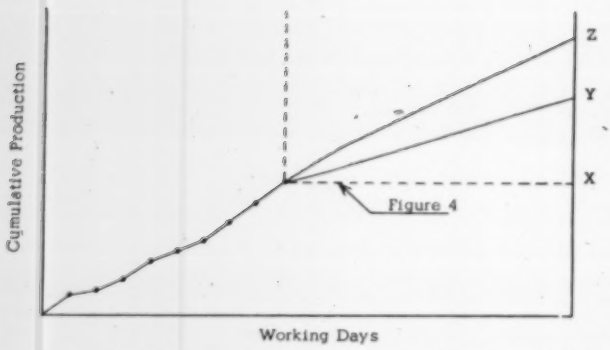

FIG. 6. Record of Cumulative Production to Nine Days before the End of the Production Period, with Two-Shift, Two Sigma Limit Lines for the Remaining Nine Days.

S_2 = Safe level of production on day N such that a two-shift schedule will yield G or more when $N = M$

a_2 = average daily two-shift production

This function is the two-shift safe operating limit shown in Figure 3. The calculation of the three-shift safe operating limit line follows the same reasoning. From a sample of days in which 3 shifts were scheduled, the mean (a_3) and standard deviation, (σ_3) of total production were calculated. Use of these values in Eq. 3. yields the equation of the three-shift safe operating limit line.

$$S_3 = G + 2\sigma_3\sqrt{M - N} - a_3(M - N) \quad S_3 \leq G \text{ Eq. 4.}$$
$$S_3 = G \quad S_3 > G$$

σ_3 = Standard deviation of daily three-shift production

a_3 = Average daily production from three shifts

S_3 = Safe level of production on day N such that a three-shift schedule will yield G or more when $N = M$.

Using functions Eq. 3 and Eq. 4. and knowing G, M, σ_3, a_3, σ_2, and a_2, it is possible to draw the safe operating limit lines at the beginning of each scheduling period.

It is important that the parameters of production, a and σ, be kept current for they can change significantly in short periods of time, especially on new equipment. Besides their importance in the calculations described above, these two values are also good indications of machine "health." Trends in these values are a good means to evaluate any change in the machine.

The use of this scheduling technique brings into clear focus the consequences of a rigid production goal over a short time period. In effect, such a goal forces over-production on the average to the extent by which production may vary during the scheduling period. The exact extent of this over-production is determined by the confidence required of meeting the production goal. After the goal is attained, however, a period of relative idleness results until a new short term estimate of required production is received.

A further analysis could be made to determine inventory effects and examine various techniques for inventory control. However, the problem encountered and the solution presented involves meeting a given goal at a given confidence level using available operating data.

A less rigid production goal, recognizing month to month variation, would allow more flexible operation and longer range planning. This might also result in lower cost, depending on the effect on finished goods inventory requirements. Another alternative would be to set a higher rigid goal but extend proportionately the time period during which it might be accomplished. This would permit more of the variation to average out and make a more stable schedule possible.

Thus the characterization of a highly mechanized production facility by this simple statistical technique quantifies an undesirable by-product of such a facility,

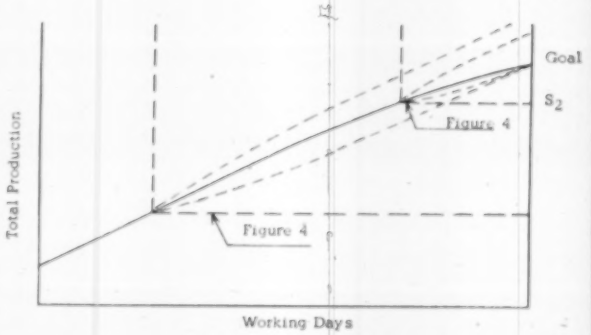

FIG. 7. Scheduling Chart with Two Sigma Limits, Calculated so that the Lower Limit Intercepts the Production Goal at the End of the Production Period.

random interruptions of production for maintenance and the resulting variations in output. With this statistical description it is possible objectively to evaluate the production required of such a facility and it would appear that traditional, rigid, short-range production requirements should be re-examined. In any case, this technique yields criteria which make it possible effectively to schedule production to meet a given goal with any desired degree of confidence.

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The Engineer and Resistance to Change

by **EDWARD V. KRICK**

Department of Industrial and Engineering Administration, Cornell University

RESISTANCE to change may be defined as an unwillingness to accept a change where the unwillingness is based upon something other than demerits of the change itself. The frequency with which such resistance is ordinarily encountered makes this a problem of primary importance to the engineer.

No doubt there are many very worthy engineering proposals that have been rejected on grounds other than their technical content. Of greater concern, however, is the high percentage of proposals that are accepted and installed and then eventually prove notably unsatisfactory, not for technical reasons, but because the people affected by the new methods have resisted and responded in such a way as to render them failures. Effective utilization of an idea does not necessarily follow because it is technically sound and officially accepted; the latter gives no assurance of the former. Resistance to change presents a formidable problem not only in getting ideas adopted, but in obtaining the cooperation of persons affected by new procedures after adoption.

TWO TYPES OF PROBLEMS

In a discussion of resistance to change it is desirable to distinguish between major technological changes and everyday shop changes. The former, typified by introduction of the continuous strip mill, is an extensive technological innovation that affects whole populations and frequently causes major economic and social problems. However important as these may be when they do occur, as Charles Walker points out in *Industrial Productivity:*

> The average industrial relations manager or, say, the president of a local, deals with a "major" technological innovation but once in a lifetime or not at all. The problems of shop changes and their disturbing effects, on the other hand, are always present.

Therefore, we shall focus our attention upon handling these everyday shop changes.

COMMON CAUSES OF RESISTANCE TO CHANGE

To better understand and fully appreciate the methods of minimizing resistance to change, it is advisable to first become familiar with the common causes of this reaction Such knowledge of the potential causes is useful in planning the introduction of changes to minimize resistance and in diagnosing and remedying situations in which resistance has been encountered after the changes have been introduced.

There is an important fact concerning "business life" that should be recognized in dealing with resistance to change problems. It is that almost every individual in an organization has some personal motives or objectives that are oftentimes in conflict with the overall objectives of the enterprise. The more common personal objectives of interest here are:

1. To attain *advancement.*
2. To be of some *importance* in the eyes of associates, superiors, family and friends.
3. To be *liked* by fellow employees.
4. To earn *(more) money.*
5. To receive some *satisfaction* from the work involved.
6. To *participate* in making decisions concerning personal welfare.
7. To attain *security* with respect to employment, position, salary, etc.[1]

The important point is this: A person is *likely* to resist a change, in spite of the fact that it is capable of increasing company profits if it threatens the above objectives. What reaction should we expect from a person if a proposed change lessens his chances for advancement, or undermines his importance, or makes him unpopular with associates and/or subordinates, or lessens his chances of earning more money, or jeopardizes his current wage level, or reduces the amount of satisfaction he receives from his work, or threatens his security of employment? Is he likely to be receptive to a change he has had no opportunity to contribute to or express his opinion on previously? Is he likely to approve a change that offers to cause him embarrassment (because he believes it is he that should have thought of the idea, perhaps long ago), or to cause him to appear negligent or ignorant?

Ordinarily, the individual is willing to make little or no personal sacrifice in the above respects for the sake of the welfare of the business. It is unrealistic to think that everyone acts at all times in the best interests of the enterprise for which he works. As a consequence of this situation, there is a considerable and surprising amount of "suboptimization" going on in the administration and operation of any enterprise.

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[1] These are not the only personal objectives, nor are they held by all, nor are they weighted the same by all.

A number of specific causes of resistance to change, most of which arise out of this practically universal conflict between personal and organizational objectives, are presented below. The intent of this outline is to provide a practical check list for preventive and diagnostic purposes.

For such purposes it is useful to distinguish between the person who has authority to accept or reject the proposal, for example, an executive or supervisor, and the person who has no voice in acceptance or rejection of the proposal but is affected by it and whose cooperation is important to successful implementation of the proposal. The latter category is composed predominantly of shop and office workers.

In the case of a person who has the authority to accept or reject the proposal, the resistance may arise from:

1. Inertia, an innate desire to retain the status quo, even where the present situation is obviously inferior. This is resistance aroused because the new method is *A* change, and has no relation to the specific proposal. Thus the supervisor, for example, opposes the new method *merely because it is different* from what he is accustomed to doing.
2. Uncertainty. Regardless of how inferior the existing method may be, at least one *knows* how it functions. However, how well a proposed change will function is a matter of prediction which is sometimes grossly in error. Any deviation from the current procedure involves a risk; there is no guarantee that the new method will bring better results after the cost of installation has been incurred. The feeling that many have is "Why should we create a potential source of trouble by introducing a new system when the existing one does work?"
3. Failure on the part of the rejector to see the need for the proposed change.
4. The proposal may not be understood by the rejector. Even though this man is not directly affected by the proposal, a failure to understand the nature and functioning of the new system may well arouse over-cautiousness, or a feeling of inferiority and resentment.
5. The fear of obsolescence. A man who has invested years of experience to build up a high level of skill, knowledge, and judgment, in administering a certain system, stands to have these fruits of experience obsoleted by adoption of a new procedure. When a new system is proposed, a fear of the inability to become proficient under the new system may well cause any man to be apprehensive as to his future value and security in that job. Under such circumstances, resistance is certainly likely. Herein lies one reason for the resistance offered by some time study administrators to the introduction and use of such techniques as predetermined motion times, work sampling, and others.
6. Loss of job content. A change may reduce the skill required, scope, importance, responsibility, authority, etc., offered by a person's job. For example, a proposed change may reduce the size of the work force supervised by the objector. Such effects are commonly referred to as job dilution. This usually reduces the prestige value of the job and the value of the person to the organization, and therefore may well arouse resistance.
7. Desire to retain favor of the work group. To avoid making life more difficult, a foreman might well be expected to act in the interest of his men and against the interests of management in passing judgment upon a proposal. Thus, if a change is unpopular with his subordinates, a supervisor is likely to resist the proposal.
8. Disinterest because a proposed change is outside the rejector's area of responsibility and concern. Expect this if the suggestion does not personally benefit the person to whom you are presenting your proposal. This may be because he just doesn't care; on the other hand, advancement in an organization is generally a competitive proposition, and allowing feathers to be put in the caps of competitors is not customary.
9. A personality conflict between the objector and the person proposing the change.
10. Resentment of outside help. For example, when an engineer is assigned to cope with a supervisor's problem, it is quite likely that the supervisor will fear a loss of prestige in the eyes of his subordinates. The implication as he sees it is that he cannot handle his own problems.
11. Resentment of criticism. This might well be the case if the person to whom you are trying to sell your proposal has originated the present method.
12. Lack of participation in formulation of the proposed change. Embarrassment at not having conceived of an idea which upon hindsight appears obvious probably will cause resentment. The feeling will probably give rise to some sort of face-saving reaction.
13. Tactless approach on the part of person making the proposal. *Sometimes a few words can make the difference.* Remember those famous last words: "That's no way to do it. . . ."
14. Lack of confidence in the ability of the person proposing the idea.
15. Inopportune timing. Rejection may have been received only because the proposal was made when the rejector was emotionally or physically upset, or when he was unusually busy, or when business was in a temporary slump, or when there was an unusually heavy demand on investment funds, or when labor relations were strained, etc.
16. A change that involves extra work, such as learning and using a more lengthy routine, may arouse resistance.

Common causes of resistance to change on the part of persons who have no voice in acceptance or rejection of a proposal but who are directly affected by it are:

1. Inertia, especially when the change is sudden and/or radical.
2. Uncertainty as to just what a change will bring. Even though the current situation may not be satisfactory to the worker, he may not care to risk the possibility of a poorer situation, such as lower pay, poorer working conditions, less desirable working mates, a more difficult job, etc.
3. Ignorance of the need for or purpose of the change. Only too often changes are made with little or no explanation to the worker, sometimes with the feeling that this is none of his business!
4. Failure to understand the new method or policy which may arouse suspicion or an insecure feeling.
5. Reluctance to exert the effort required to learn a new procedure.
6. A loss of job content. A change that means a reduction in skill required, or of importance, or of responsibility, may readily arouse resistance. Aside from the important fact that job dilution usually reduces the prestige value of the job and the value of the job holder to the company, a job is more likely to be more monotonous as it becomes simplified and shortened.

7. Pressure of the work group. Each member of the work group often reacts so as not to offend the others, even though as an individual he does not feel as strongly as his actions would indicate. Every work group has certain ingrained policies, some expressed and others implied, which constitute a "code of behavior" and which help to govern the actions and reactions of its members. A person's reaction to a change is usually influenced by what he knows or anticipates the group wants, even to the point of sacrificing personal gain for continued approval of his co-workers.
8. Fear of economic insecurity. The change may result in displacement or a reduction in earnings. The latter may arise in any one or more of the following ways:
   a. A reduction in job classification.
   b. "Rate cutting" which may accompany the change. The company frequently uses a change in method as an opportunity to "bring the standard in line" on the job. If there has been a loose time standard on the operation, this will probably be remedied when a standard is set for the new method. Thus, a change in method may well be affecting the worker's economic status in this informal way. Under such circumstances, resistance to the change is certainly to be expected.
   c. Inability to master the new method, or at least to reach the level of proficiency that the person had attained under the replaced method. This is particularly true of older operators.
9. Alteration of social relationships, or fear of same, such as breakup of a closely knit work group, introduction of a method that prohibits conversation while working, etc.
10. An antagonistic attitude toward the person introducing the change or what he represents. It may be a personal antagonism, or it may be an antagonism toward his function, or management in general. The latter, an attitude that is often hostile, causes individuals and groups to resist almost any change, in fact, almost everything but the pay check, that comes from the management direction. This might be called resistance on general principles.
11. Origination and/or introduction by an "outsider." Executives, higher supervisors, and engineers are usually considered as external to the worker's economic and social group, in fact, they are frequently quite unpopular. Resentment is quite likely if such persons introduce a change.
12. No participation in formulation of the new method or policy. It appears to workers that changes are often adopted without their best interests in mind. They want an opportunity to express and protect these interests, to have a part in deciding what they must do and how.
13. Tactless approach on the part of the person introducing the change.
14. Inopportune timing. Resistance may have been received only because the change was introduced when feeling was running high between the work group and management, or because the change was made with little or no advance notice, etc.

SUGGESTED METHODS OF MINIMIZING RESISTANCE TO CHANGE

The following recommendations should be observed in planning the method of introducing an idea *and* in modifying the idea to make it more saleable and palatable.

These measures apply both to the person holding authority to accept or reject your proposal and to the person who has no choice in the matter (but is affected by the change):

1. Convincingly *explain the need* for the change.
2. Thoroughly *explain the nature* of the change. Use straightforward, clear, well-organized language to assure that persons understand the method or policy. Don't overlook the importance of this understanding. Tailor your written and oral reports to suit the particular reader.
3. Facilitate participation, or at least the *feeling of participation*, in formulation of the proposed method. In general, people are concerned about making their own ideas and recommendations succeed, whereas they have a neutral or negative attitude toward the ideas of others. The feeling of participation may be imparted in several ways:
   a. *Consult* people for information, opinions, and suggestions. Show a real interest in what they have to say. Seek advice even if you think you don't need it and you may benefit in more ways than one. The mere opportunity to express himself, the mere request to contribute may well give a person a feeling of participation in formulation of a new method, even though none of his ideas have actually been included in the new setup.
   b. Of course, whenever possible, *include the worthwhile suggestions* of others in your final proposal and give credit to the appropriate individuals.
   c. In some instances it may be advisable or even necessary to incorporate a person's idea that is inferior to that which you would otherwise use, in order to get him into the act. This "sugaring up" or compromising of proposals in order to get them accepted and to minimize adverse reactions will probably make the difference between success and failure on many occasions.
4. Use a *tactful* approach in introducing your proposal. Watch your wording, mannerisms, and above all, avoid criticism or anything that may be construed as such.
5. Watch your timing.
   a. In attempting to gain adoption of an idea, avoid making your proposal when the recipient is upset, busy, etc. Allow sufficient time for him to think it over, don't rush the thing. Who knows, sometime later he may concede or propose the idea as his.
   b. In introducing a new metohd or policy to employees, provide ample advance notice. Avoid introducing certain changes when labor relations are abnormally strained.
6. In the case of major changes, if possible introduce the change in stages, to make it easier to adjust and to overcome inertia. And, too, the mere magnitude of some proposals sometimes frightens managers and arouses objection. In introducing a major overhaul in stages, it is wise to introduce first those changes that you are most confident will yield successful results.
7. Instill a consciousness of resistance to change. If a person is aware of the causes, manifestations, and frequency of this non-rational behavior, he will be less inclined to resist changes. This seems to be an effective counter measure, at least in the case of supervisors, managers, and executives.
8. Educate as to the importance of change to the economic welfare of the enterprise. Although popular, this is probably an over-rated measure in reducing worker resistance to change.
9. In attempting to gain acceptance, capitalize on the features that provide the most personal benefit to the person(s) you are trying to sell.
10. If possible, maneuver by appropriate questioning, a prospective rejector into "thinking" of (your) idea himself. This procedure of "planting" the idea in his mind is usually effective if it can be worked. The difficulty is that this is not easily accomplished, nor are we generally that noble

in that we would make a habit of planting our ideas in other persons' minds.

These measures apply mainly to minimizing resistance by persons directly affected by changes:

1. Show a personal interest in the welfare of those affected by the change by:
   a. Paying particular attention to older persons, close social relationships, individual differences, etc.
   b. Finding equivalent jobs for displaced employees, where they may make maximum use of their previously developed skills.
   c. Providing, if possible, guarantees as to security of employment and earnings.
   d. Providing thorough training in the new procedure.
   e. Attempting to avoid drastic reductions in job content. If the skill, performance time, or responsibility have been reduced, perhaps this may be counteracted by allowing the worker to do his own setup, inspection, planning of jobs, etc., or by combining several short cycle jobs into one.
2. Whenever possible, have changes announced and introduced by the immediate supervisors of those affected. There are several disadvantages to the bypassing of foremen in introducing changes.

PLANNING VS. DIAGNOSIS

It is important that the foregoing material on minimization of resistance to change be applied from the moment you begin a particular project, and that it be kept in mind continually, right through to final acceptance and installation of your proposal. Don't neglect the matter until you find yourself in the position of having completed an excellent solution to a problem, excellent in every respect except that the proper personnel won't accept it. Nor should you exclude consideration of this matter as you work out a problem, until you are ready to propose your solution, then stop to plan your "acceptance gaining strategy," for it may already be too late. Instead, you should give careful consideration from the outset, to your behavior, your manner of dealing with various personnel, the features of your proposal, etc., with the objective of minimizing the chances of subsequent rejection of your ideas. Thus, attention to this problem of resistance to change should be, insofar as possible, in the form of planning to minimize the likelihood of its occurrence, as opposed to the diagnosing of unfortunate situations to learn why rejection has occurred and what might be done, if anything, to reverse these situations.

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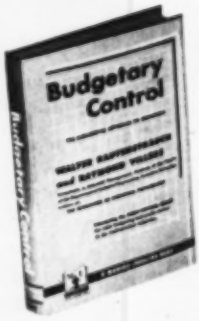

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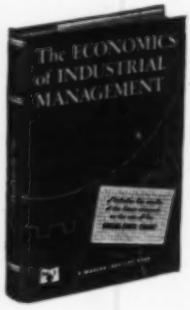

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Statistical Decision Theory as a Method for Information Processing

by HARVEY M. WAGNER[1]

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ECONOMISTS, statisticians, and practitioners of operations research frequently meet nearly identical problems in their respective studies. Once the similarities are recognized, the solutions advanced by one group of professionals often turn out to be useful to others in different disciplines. The belief expressed here is that statistical decision theory provides both an enlightening and a unifying approach to problems concerned with decision making in the face of uncertainty. As will be pointed out subsequently, statistical decision theory is by no means the last word on such problems—at least at its present state of development—but the approach seems to ask the right questions and accurately pinpoints the areas of difficulty.

The advance which decision theory makes over previous methods in mathematical statistics is that the economic consequences of an action are explicitly taken into account. In other words, the theory goes beyond statements about probabilities of making various errors, and incorporates both the relative losses from such errors as well as the costs of processing information in order to reduce the likelihood of mistakes. One important consequence claimed by decision theorists is that by such analysis it is possible to unify various subfields in statistics into a single conceptual framework. For the moment we shall refrain from stating the alleged disadvantages of the theory.

The general problem of decision making, whether studied by a statistician, an economist, or an operations researcher, can conveniently be stated as follows: The decision maker has to choose some course of action out of several open to him.[2] Such an action may pertain to an existing state of affairs or to future events; in any case, the Decision Maker does not know what the true state really is, and hence he has to choose an action under conditions of uncertainty. The economic consequences of the situation are a joint function of the action taken and the true but, at present, unknown state of affairs. It is useful to think of this situation as a game played by Nature, who chooses the underlying state, and the Statistician (or the decision maker), who selects an action. Usually the Decision Maker, by means of relatively costly data processing, is able to obtain some information about the strategy Nature has selected. The Decision Maker must balance the costs of data processing with the costs of making mistakes at a frequency which could potentially be lowered if more information were available. The data conceivably available to the Decision Maker may or may not be able to give complete information as to Nature's strategy.

The above formulation applies easily to the case of a management group making some decision about the company's sales, production, or investment policies by "sampling" information. The cost of sampling of course may include the use of an electronic computer as well as the expense of collecting data. Consequently a wide variety of data processing problems may potentially be handled by decision theory techniques.

OUTLINE OF A DECISION THEORY PROBLEM

Statistical decision theory, not unlike schools of thought in economics, mathematics, or philosophy, is based on a system of axioms. These postulates are far from inconsequential, but space limitations prohibit a lengthy discussion of the axioms. Briefly, their main implication is that it is possible to assign numerical values to the joint result of the Decision Maker's and Nature's strategies; these numerical values are what we have been calling the "economic consequences" of the final situation from the point of view of the Decision Maker.[3] Further, *given Nature's choice*, if one action results in a numerical value of 10, say, and another action results in

[1] This paper was presented at the Data Processing and Management Information Conference, Massachusetts Institute of Technology, July 15-19, 1957. The author owes more than the usual debt of gratitude to Professors Herman Chernoff and Lincoln Moses, Stanford University, for permission to read their forthcoming book on decision theory (4).

[2] We shall not be concerned with the organizational or team problems of decision making. We assume that the individual, team, organization, etc., all have identical goals.

[3] In the technical literature the numerical indicator is called the Statistician's utility function. Luce and Raiffa give a detailed discussion of the axiom system in game and decision theory (7); for a summary treatment, see H. M. Wagner, "Advances in Game Theory," *American Economic Review*, June, 1958, p. 368-387.

TABLE 1

The Decision Maker's Economic Evaluation of Possible Actions

		Possible Actions				
		a_1	a_2	$\cdots$	a_j	$\cdots$
States of Nature	N_1	$u(N_1, a_1)$	$u(N_1, a_2)$	$\cdots$	$u(N_1, a_j)$	$\cdots$
	N_2	$u(N_2, a_1)$	$u(N_2, a_2)$	$\cdots$	$u(N_2, a_j)$	$\cdots$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	N_i	$u(N_i, a_1)$	$u(N_i, a_2)$	$\cdots$	$u(N_i, a_j)$	$\cdots$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

a numerical value of 20, then the combined "action" of flipping a fair coin, so that on heads the first action is taken, and on tails the second action is taken, has the numerical value of the arithmetical average $\frac{1}{2} \times 10 + \frac{1}{2} \times 20 = 15$. In most elementary presentations of the theory of games, the numerical value is usually assumed to be the monetary consequence or payoff of the situation. Such an *additional* assumption may or may not be tenable in a particular case; but in any event, decision theory assumes that some numerical indicator of preference for various situations is available, and that it is meaningful to take probability averages of these numbers in evaluating the relative merit of different combinations of uncertain outcomes.

It is most important to realize that the preference indicator refers to an evaluation of a risky situation *before* the final outcome has been determined, i.e., at the point of time when the Decision Maker must make a decision in the face of uncertainty. Thus in the previous example, the value 15 is associated with the gamble of an even chance of receiving 10 *or* 20. Comparing this gamble to a nonrandom event having a numerical value of 12, the Decision Maker favors the riskier situation according to his preference indicator. Although the before-the-fact evaluation of tossing the coin is 15, once the Decision Maker has made the final decision to gamble, he receives either 10 *or* 20. The power of the underlying axiomatization process is that it guarantees an evaluation of any complex probability situation in terms of a single number, that number being the corresponding probability weighted average of the indicator values for each possible outcome.

For expositional simplicity assume that Nature and the Decision Maker have a finite number of simple alternatives: Nature's choices are $N_1, N_2, \ldots, N_i \ldots$, and the Decision Maker's actions are $a_1, a_2, \ldots, a_j, \ldots$. The Decision Maker's numerical indicator of the outcome of Nature's selecting N_i and his taking action a_j is denoted as $u(N_i, a_j)$. The entire set of consequences can be displayed in matrix form, Table 1.

Suppose that the Decision Maker has the opportunity of performing a single costless experiment. The experiment may be complicated and may offer a variety of bits of information, but assume that the outcome of the experiment can be summarized by a "vector" symbol z_k, and that there are only a finite number of z_k. For example, one experiment might be a yes-no questionnaire; in this event z_k would be a "vector" of information yielding the number of yes answers to the first question, to the second question, . . ., to the n-th question.

By assumption, the data z_k are related to N_i. More precisely, suppose that, *given* any N_i, the probability of observing z_k is known, which is denoted as the "conditional" probability $p(z_k \mid N_i)$. Once again the conditional probabilities can be arrayed by means of a table. See Table 2. Each row in the matrix indicates the conditional probability of observing every z_k given that N_i is the true state of nature.

Next we define the notion of a simple strategy for the Decision Maker. Recall that the Decision Maker may observe any z_k and accordingly take any action a_j. Conceptually all possible simple strategies available can be formulated by listing all combinations of actions associated with observations, Table 3. Each row in the matrix is a simple strategy, which specifies the action to be taken if a z_k is observed. Altogether the number of sim-

TABLE 2

Conditional Probabilities $p(z_k \mid N_i)$

		Possible Observations					
		z_1	z_2	$\cdots$	z_k	$\cdots$	Σ
States of Nature	N_1	$p(z_1 \mid N_1)$	$p(z_2 \mid N_1)$	$\cdots$	$p(z_k \mid N_1)$	$\cdots$	$\Sigma p(z_k \mid N_1) = 1$
	N_2	$p(z_1 \mid N_2)$	$p(z_2 \mid N_2)$	$\cdots$	$p(z_k \mid N_2)$	$\cdots$	$\Sigma p(z_k \mid N_2) = 1$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	N_i	$p(z_1 \mid N_i)$	$p(z_2 \mid N_i)$	$\cdots$	$p(z_k \mid N_i)$	$\cdots$	$\Sigma p(z_k \mid N_i) = 1$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

ple strategies is: the number of actions raised to the power the number of possible observations. For example, if there are two actions and five possible observations, then there are $2^5 = 32$ simple strategies.

From Tables 2 and 3 we are able to construct a matrix for each strategy s_k, which yields the probability $p(a_j \mid N_i, s_k)$ of taking a particular action a_j, given Nature's N_i and strategy s_k, Table 4.

Finally Tables 4 and 1 are combined to produce a table showing the *expected* or average numerical values for each pair of strategies. Since for a particular strategy Table 4 gives the probability of taking an action for each state of nature, and since Exhibit 1 contains the numerical consequences associated with each action and state of nature, we average the numerical outcomes and enter them in Table 5 as $U(N_i, s_k) =$

$$\sum_j p(a_j \mid N_i, s_k) u(N_i, a_j).$$

Table 5 completely embodies the problem defined. It shows all the simple strategies open to the Decision Maker and to Nature. In addition to these simple strategies, each player can also elect to "randomize" between the simple strategies, i.e., to select each simple strategy according to a certain probability.

It is now appropriate to discuss the difficult topic of what is a good strategy for the Decision Maker. It should be stated at the outset that this a debatable subject, and various alternative suggestions have been put forth. Only a few of them will be briefly explained; References (3), (7) and (10) contain more complete treatments. One proposal, a poor one indeed, based on a "play safe" notion, is to ignore the data and pick a "minimax" action which protects against the worst possible selection of N_i by Nature. Using either Table 1 or those strategies in Table 5 which ignore z_k (i.e., pick the same a_j for all z_k), determine the worst numerical outcome that may arise with the selection of an a_j; then choose that particular a_j which assures the best out of the "worst" values previously found.

An extension of the above procedure is to use *all* the strategies in Table 5, and to select the "minimax" from these strategies, now specifically allowing probability mixtures or randomization between strategies, if desirable. The numerical value associated with such a generalized minimax strategy is usually an average value of the $U(N_i, s_k)$ components in Table 5, which in turn are averages derived from Tables 1 and 4.

If the Decision Maker has some a priori information (say, from past relevant experience and data) that Nature selects N_i with probability w_i, then the s_k such that

$$\sum_i w_i U(N_i, s_k)$$

is maximized defines an optimal selection, which is called a Bayes strategy. Even if a priori probabilities about Nature are not known, it is clear that the Decision Maker should consider only strategies which are at least optimal for some set of a priori probabilities. This class of strategies, which here will be called the admissible strategies,[4] is usually considerably narrower than all the simple and mixed strategies implied by Table 5. Interestingly enough, for each possible set of a priori probabilities over the N_i, there is at least one *simple* strategy s_k which is optimal for the Decision Maker. In special cases it is possible by appealing to "likelihood ratio" manipulations to determine all the admissible strategies rather easily without the complete enumeration of Tables 3 and 5.

TABLE 3
Simple Strategies

Decision Maker's Strategies	Possible Observations							
	z_1	z_2	z_3	· · ·	z_k	· · ·	z_n
s_1	a_{11}	a_{12}	a_{13}	· · ·	a_{1k}	· · ·	a_{1n}
s_2	a_{21}	a_{22}	a_{23}	· · ·	a_{2k}	· · ·	a_{2n}
s_3	a_{31}	a_{32}	a_{33}	· · ·	a_{3k}	· · ·	a_{3n}
·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·
s_k	a_{k1}	a_{k2}	a_{k3}	· · ·	a_{kk}	· · ·	a_{kn}
·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·

a_{kk} action to be taken using strategy s_k if z_k is observed.

The general framework of a statistical game may now be summarized: The Decision Maker and Nature are the two players, each with certain possible strategies or actions; there is a determinate economic evaluation for the Decision Maker depending on the outcome of both players' selection of strategies; it is possible for the Decision Maker to perform experiments and observe information pertaining to Nature's choice of a strategy; out of all possible strategies for the Decision Maker, attention is confined to the class of admissible strategies, i.e., a strategy which is Bayes for at least some a priori probabilities for Nature. It can be shown that one such admissible strategy is that associated with the minimax average numerical evaluation, and which may be a good strategy if the Decision Maker has *no* a priori information about Nature. In the next section we introduce the cost of sampling, which previously we have ignored.

A CLOSER LOOK AT THE DATA PROCESSING OPERATION

The effects of experimentation will now be more carefully examined to demonstrate an efficient method of ex-

[4] In mathematical statistics there is a fine distinction between the classes of admissible strategies and of Bayes strategies; further, in special games no admissible strategies may exist. But we shall not be concerned with such technical matters in this paper.

TABLE 4

Action Probabilities for Strategy s_k

		Possible Actions					
		a_1	a_2	$\cdots$	a_j	$\cdots$	Σ
States of Nature	N_1	$p(a_1 \mid N_1, s_k)$	$p(a_2 \mid N_1, s_k)$	$\cdots$	$p(a_j \mid N_1, s_k)$	$\cdots$	$\Sigma p(a_j \mid N_1, s_k) = 1$
	N_2	$p(a_1 \mid N_2, s_k)$	$p(a_2 \mid N_2, s_k)$	$\cdots$	$p(a_j \mid N_2, s_k)$	$\cdots$	$\Sigma p(a_j \mid N_2, s_k) = 1$
	.	.	.	.	.	.	.
	.	.	.	.	.	.	.
	.	.	.	.	.	.	.
	N_i	$p(a_1 \mid N_i, s_k)$	$p(a_2 \mid N_i, s_k)$	$\cdots$	$p(a_j \mid N_i, s_k)$	$\cdots$	$\Sigma p(a_j \mid N_i, s_k) = 1$
	.	.	.	.	.	.	.
	.	.	.	.	.	.	.
	.	.	.	.	.	.	.

tracting information out of the sample data and to delineate the economic consequences of obtaining different amounts of costly information.

Although the conceptual framework advanced above is complete, the extent of enumeration of simple strategies needed to accomplish the analysis, even for ordinary sized problems, may be overwhelming if some shortcuts are not available; furthermore, much of the effort expended in the exhaustive approach is on strategies which turn out to be inadmissible. Fortunately, probability theory permits certain important simplifications in the procedures previously outlined.

In the case where no experimental data exist but a priori probabilities for N_i are available, it has been stated that with Table 1 the probability averages over the different $u(N_i, a_j)$ for each action a_j would be calculated, and the correct action would be the one yielding the highest average. If some experimental data z_k do exist, the procedure outlined for Table 5 may be equivalently performed by using the experimental data to transform the a priori probabilities into what are called a posteriori probabilities; the latter probabilities are then applied to the entries in Table 1 just as the a priori probabilities would be applied in the no experimental data case.

From Table 2 the conditional probability $p(z_k \mid N_i)$ of observing z_k given N_i is known, and w_i denotes the a priori probability of N_i. As defined by probability theory (5) (9)

$$p(z_k \mid N_i) = p(z_k \text{ and } N_i)/w_i.$$

In other words, the conditional probability of z_k, given N_i, is equal to the joint probability of *both* z_k and N_i occurring divided by the a priori probability of N_i. Rearranging terms give

$$w_i p(z_k \mid N_i) = p(z_k \text{ and } N_i).$$

The event of observing z_k is the "sum" of the mutually exclusive and completely exhaustive events of obtaining z_k when N_1 is the true state of nature, z_k when N_2 is the true state of nature, . . . , z_k when N_i is the true state of nature, etc. In probability terms

$$\begin{aligned} p(z_k) &= p(z_k \text{ and } N_1) + p(z_k \text{ and } N_2) + \ldots \\ &\quad + p(z_k \text{ and } N_i) + \ldots \\ &= w_1 p(z_k \mid N_1) + w_2 p(z_k \mid N_2) + \ldots \\ &\quad + w_i p(z_k \mid N_i) + \ldots \end{aligned}$$

Therefore the above formulas are combined to derive the a posteriori probability of N_i given z_k

$$\begin{aligned} p(N_i \mid z_k) &= p(z_k \text{ and } N_i)/p(z_k), \text{ by definition} \\ &= w_i p(z_k \mid N_i)/w_1 p(z_k \mid N_1) + w_2 p \\ &\quad (z_k \mid N_2) + \ldots + w_i p(z_k \mid N_i) + \ldots \\ &= \overline{w_i} \end{aligned}$$

which numerically is w_i transformed to an a posteriori probability by multiplying by an appropriate factor that is a function of the actual observed z_k. It can be proved that the Bayes procedure as outlined with Tables 1-5 is equivalent to the procedure of applying the a posteriori probabilities $\overline{w_i}$ to Table 1. It can also be shown that if successive experiments are performed, e.g., if the information in the vector z_k is actually gotten single experiment by experiment, then the correct procedure is continually to "revise" or to "update" the a posteriori probabilities using the information gained from the new experimental data.

Is the suggested procedure a shortcut? Recall in Table 3 it was necessary to construct a complete listing of every possible strategy; the number of such strategies depended on the number of *all possible* z_k which could be

TABLE 5

Average Economic Evaluation

		Decision Maker's Strategies				
		s_1	s_2	$\cdots$	s_k	$\cdots$
States of Nature	N_1	$U(N_1, s_1)$	$U(N_1, s_2)$	$\cdots$	$U(N_1, s_k)$	$\cdots$
	N_2	$U(N_2, s_1)$	$U(N_2, s_2)$	$\cdots$	$U(N_2, s_k)$	$\cdots$
	.	.	.	.	.	.
	.	.	.	.	.	.
	.	.	.	.	.	.
	N_i	$U(N_i, s_1)$	$U(N_i, s_2)$	$\cdots$	$U(N_i, s_k)$	$\cdots$
	.	.	.	.	.	.
	.	.	.	.	.	.
	.	.	.	.	.	.

observed. The shortcut is that a Bayes procedure need only call for certain computations utilizing an *actually* observed z_k; therefore in practice it is not necessary to list all strategies taking into account any eventuality, but rather to make computations based on the particular result of the experiment. Analogous reasoning applies to the results from a sequence of experiments.

We finally come to the important point of when costly experimentation or data processing should cease and an action be taken. The case of a sequential sampling procedure is discussed here; the simpler case of a fixed sample size plan is examined in the following section The *mathematical* condition for the correct stopping place in a sequential game is well defined. The analysis, which is closely related to Bellman's principle of optimality in dynamic programming (2), is as follows: If a decision is made at the end of some stage of experimentation, the numerical value for the Bayes procedure is found from an average of the a posteriori probabilities and the entries in Table 1. If further experimentation is undertaken, the result will be a random variable, and new a posteriori probabilities will be derived. After an additional observation is processed, a similar calculation is once again made whether further sampling should follow or an action be taken. Because the outcome of an additional observation is a random variable, the decision of what to do next will also be random. The process is repeated until further sampling is uneconomical.

Whenever inspection continues, the cost of making each experiment, reckoned in numerical values consistent with those in Table 1, must be subtracted in order to arrive at the net valuation of further experimentation. Usually more information about Nature's strategy will increase the expected Bayes average valuation. The question is whether the increment in economic value of more data is offset by the cost of obtaining it. Since the experimental results are random variables, at each stage of the analysis a complicated procedure is needed for computing averages reflecting the valuation of some particular overall sampling strategy. The final decision about a new experiment rests on a comparison of the present a posteriori Bayes average value and the net expected value if another experiment is achieved *and the Decision Maker acts optimally thereafter.* As Blackwell and Girshick (3) have demonstrated, in certain special cases (analogous to elementary cases in sequential analysis) the operating procedures for a "sequential statistical game" are fairly simple. In general, a computing procedure for solving such problems is very complex.

AN ILLUSTRATION IN QUALITY CONTROL

An application in the area of quality control will serve to illustrate the decision theory technique.[5] Small lots of a complex assembly item are to be subjected to an acceptance sampling procedure. It is known from experience that the number of defects per item occurs according to a Poisson probability distribution; and for the sake of simplicity, it is postulated here that Nature "produces" lots after selecting a Poisson distribution with an average of either 10 or 20 defects per 100 items.[6] In the former case, the lots are acceptable, and in the latter case unacceptable. Table 6 contains the Decision Maker's payoff matrix. In this example, instead of representing losses as negative numbers employed in a maximizing operation, they are treated as positive numbers, and strategies which minimize loss are to be investigated. It is *assumed* that these monetary outcomes are good approximations to the Decision Maker's "utilities."

TABLE 6
Decision Maker's Losses[7]

		Possible Actions	
		a_1 Accept Lot	a_2 Reject Lot
States of Nature	N_1 = 10 defects per 100 items	0	\$10
	N_2 = 20 defects per 100 items	\$20	0

The minimax strategy for the Decision Maker, if he does no sampling, is to select a_1 with probability ⅓ and a_2 with probability ⅔. The expected value of the outcome, \$6.66, is then independent of Nature's strategy. If the a priori probability $w_1 = ¾$ and $w_2 = ¼$, then a_1 is the optimal action, giving an expected value of \$5.00.

Although the size of a sample is a variable which should be subject to economic analysis in a proposed statistical procedure, assume that for various reasons only 2 items drawn randomly out of the lot are to be inspected. The sample observations will be classified into three categories: $z_1 = 0$ defects, $z_2 = 1$ defect, $z_3 = 2$ or more defects (if two defects are found in either or both items, inspection ceases). The conditional probabilities for z_k are shown in Table 7.[8]

There are 2 possible actions and 3 possible observations; hence $2^3 = 8$ simple strategies exist, Table 8. Strategy s_4, for example, specifies selecting action a_1 if z_1 occurs, and a_2 otherwise. If N_1 is the true state of nature,

[5] For a challenging presentation of quality control applied to data processing problems of an accounting nature, see L. L. Vance and J. Neter, *Statistical Sampling for Auditors and Accountants*, Wiley, New York, 1956.

[6] We utilize the distinction employed in quality control of defect vs. defective. The latter is defined in terms of the particular number of allowable defects per item. See E. L. Grant, *Statistical Quality Control*, McGraw-Hill, New York, 1952.

[7] It is purely coincidental in this example that there is a correspondence between the values for the losses and the number of defects per 100 items.

[8] If the number of defects in 100 items has a Poisson distribution with an average q, then it is postulated that the number of defects in 2 items is distributed as a Poisson with an average 2q/100.

TABLE 7

Conditional Probabilities

	Possible Observations		
	z_1 = 0 defects in 2 items	z_2 = 1 defect in 2 items	z_3 = 2 or more defects in 2 items
States of Nature N_1	.82	.16	.02
States of Nature N_2	.67	.27	.06

then z_1 occurs with probability .82, and consequently action a_1 is taken with probability .82. Table 9 gives the action probabilities for each strategy.[9]

Finally Table 10 combines the previous matrices to give the expected or average losses for each of the strategies. A first glance at Table 10 does not reveal which strategies, if any, are inadmissible; a graphical analysis aids in the process, Figure 1. The expected losses are plotted as two coordinate points with reference to axes for N_1 and N_2. The bottom boundary, which is the lowest convex-to-the-origin boundary defined by strategy points, has the admissible strategies as vertices: s_1, s_2, s_4, s_8.[10]

The minimax strategy, found at the intersection of the bottom boundary and a 45° line through the origin, is to select s_4 with probability .46 and s_8 with probability .54. Given a priori probabilities, the corresponding Bayes strategy is found either by applying the probabilities to Table 10, or by finding at which of the admissible strategies it is possible to construct a *tangent* line with slope $-w_2/w_1$. If $w_1 = 3/4$ and $w_2 = 1/4$, s_4 is the optimal strategy.

TABLE 8

Simple Strategies

Decision Maker's Strategies	Possible Observations z_1	z_2	z_3
s_1	a_1	a_1	a_1
s_2	a_1	a_1	a_2
s_3	a_1	a_2	a_1
s_4	a_1	a_2	a_2
s_5	a_2	a_1	a_1
s_6	a_2	a_1	a_2
s_7	a_2	a_2	a_1
s_8	a_2	a_2	a_2

[9] The mathematician states that each strategy defines a "mapping" from the sample space to the action space.

[10] An alternative delineation of admissible strategies may be found in J. D. Williams, *The Compleat Strategyst*, McGraw-Hill, 1954, pp. 71-72.

If a minimax procedure is to be employed, it has been stated that the expected loss without any data is \$6.66; with data, the minimax expected loss becomes \$6.26. Therefore using a minimax strategy throughout, it does not pay to take a sample of 2 items unless the sampling cost is less than \$.40.[11] In the case of $w_1 = 3/4$ and $w_2 = 1/4$, without data the expected loss is \$5.00, and with data is \$4.70. Hence with this a priori information it pays to inspect two items only if the cost of observation is less than \$.30. Such considerations are at the heart of selecting a single stage sample size or a sequential sampling procedure.[12]

TABLE 9

Action Probabilities for Simple Strategies

	Decision Maker's Strategies s_1		s_2		s_3		s_4	
	a_1	a_2	a_1	a_2	a_1	a_2	a_1	a_2
States of Nature N_1	1.00	0	.98	.02	.84	.16	.82	.18
States of Nature N_2	1.00	0	.94	.06	.73	.27	.67	.33

	s_5		s_6		s_7		s_8	
	a_1	a_2	a_1	a_2	a_1	a_2	a_1	a_2
States of Nature N_1	.18	.82	.16	.84	.02	.98	0	1.00
States of Nature N_2	.33	.67	.27	.73	.06	.94	0	1.00

The use of a posteriori probabilities to arrive at a procedure identical to the admissible strategy defined in Table 10 is illustrated with $w_1 = 3/4$ and $w_2 = 1/4$, for which s_4 is optimal.

If z_1 is observed

$$\bar{w}_1 = \frac{3/4 \times .82}{3/4 \times .82 + 1/4 \times .67} = .79, \bar{w}_2 = .21;$$ upon applying $\bar{w}_1$ and $\bar{w}_2$ to Table 6, a_1 is found optimal.

If z_2 is observed

$$\bar{w}_1 = \frac{3/4 \times .16}{3/4 \times .16 + 1/4 \times .27} = .64, \bar{w}_2 = .36,$$ and a_2 is optimal.

If z_3 is observed

$$\bar{w}_1 = \frac{3/4 \times .02}{3/4 \times .02 + 1/4 \times .06} = .50, \bar{w}_2 = .50,$$ and a_2 is optimal.

[11] This statement must be qualified if there is some value in collecting data, say, for making a future estimate of the a priori probabilities.

[12] As the reader may verify, increasing the sample size has the effect of lowering the boundary line in Figure 1 toward the origin. But the marginal value of successive observations varies with the form of the probability distribution, the sample size, and the a priori probabilities. Hence depending on the aforementioned considerations and data processing costs, it may, for example, pay to take two observations where it would not be economical to take one.

TABLE 10

Average Economic Evaluation in Dollars

		Decision Maker's Strategies							
		s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8
States of Nature	N_1	0	.20	1.60	1.80	8.20	8.40	9.80	10.00
	N_2	20.00	18.80	14.60	13.40	6.60	5.40	1.20	0

SUMMARY AND EVALUATION OF THE DECISION THEORY APPROACH

As claimed earlier, the statistical decision theory approach to data processing seems to isolate the crucial points of decision making problems. The outcome of the Decision Maker's action is a function of not only what he does but what the true state of nature is. In spite of the difficulty of measuring economic consequences of different situations, it seems necessary to assume some sort of economic evaluation in order to arrive at any semblance of rationality in a systematic approach to decision making. The decision theory technique "automatically" weighs the different economic considerations involved in taking actions and gathering information.

Some of the serious drawbacks which appear in the suggested approach should be discussed. It is very important to realize that the limitations cited below may very well apply to *any* systematic method. Criticisms have been made at several levels of analysis. One set of criticisms concerns (a) the possibility of setting up a meaningful game in the first place, and (b) the feasibility of placing economic evaluations on different outcomes. The latter is partly answered by the reply that *any* statistical procedure has in it either an implicit or an explicit economic evaluation of outcomes. It is more realistic (and courageous!) to make such considerations explicit rather than implicit. The former argument, for example, questions the notions and assumptions involved in Table 2. Whether the requisite probability information is available is a factual matter to be determined for various situations. When such information is lacking, one should immediately be on guard in judging alternative approaches.

A second level of difficulty is the amount of mathematical manipulations necessary to obtain an answer. This criticism includes (a) the high level of theoretical mathematics demanded to analyze a statistical game, (b) as a consequence, the concentrated effort needed to attain new theoretical answers, and (c) the difficult computations required to solve a particular case. Persons familiar with dynamic programming will recognize that, although the latter technique is a very powerful conceptual mode of analysis, even modern-day high speed computers are not economically able to apply, to particular cases, some of the theoretical results which have been found (6). Thus decision theory possibly may become a helpful way of taking a first look at a problem or checking an approximate solution.

A third level of difficulty pertains to the selection of a good strategy. Often a priori probabilities of N_i are not known, and correspondingly a Bayes solution is not defined. One answer given to this criticism is that sufficient experimentation will result in a posteriori information "swamping" the a priori assumptions. Such an answer is hardly a convincing defense of the approach. Statisticians, much like economists writing in the area of "new welfare economics (1)," have often contented themselves with merely characterizing the *class* of admissible strategies, with the view that this is the class containing all rational strategies. But the practicing statistician will undoubtedly want some further help on choosing one strategy out of this class, and some indication of how his present operating procedures compare with those suggested by the decision theorists.

The decision theory approach presents a challenging and comprehensive way of looking at data processing problems. Surely any alternative approach should be required to answer the questions posed by decision theory. It remains to be seen whether decision theory has posed all of the essential questions, and furthermore

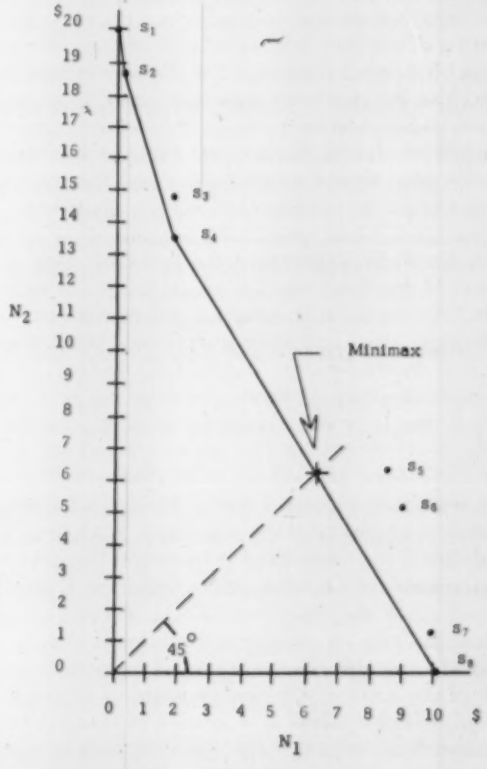

FIG. 1

whether it will be able to answer those queries which already have been formulated.

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Inventory Control—Exploiting the Electronic Data Processor in the Air Force

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THE electronic data processor (EDP) is currently being applied in helping the Air Force logistician work through the paperwork bottlenecks which arise in the world-wide, large volume, high value business that he must control. This paper will discuss an Air Force logistical EDP application in the hope that we may be opening new vistas for the Industrial Engineer. No attempt will be made to dwell on the glorifying aspects of computer usage, nor to spend time describing the great potentials computers hold in store for us. Rather, the paper will attempt to describe what we are actually doing and the great pains we take to get the machine to do our job effectively.

Although the case presented is in terms of the specifics of an Air Force application, the transformation to the context of any large business organization can be easily made. The reader will recognize general characteristics of the application, and many specific ones, which describe standard inventory and distribution control systems. Moreover, the solution herein described can be as applicable to the large commercial house as it is to the Air Force.

It is the scope and volume of this job which makes a large scale data processing system necessary for effective execution and control of the procedures. Processors of less capability in logic and speed suffice where less activity or fewer automated decisions characterize the application. But whatever the processing system, manual or mechanized, the system designer is required to specify each detail of every procedure which must be carried out, and each of the items of information required to satisfy the system objectives. Just as a posting clerk must be told the procedural steps to follow in implementing a policy, so must a computing machine have its procedures spelled out. The consequence of missing any step is a breakdown, or circumvention, of a policy. The strength of the large scale computer with its powerful logical ability and extremely high speeds is that more steps akin to managerial and supervisory level decisions can be associated with routine clerical operations than can be accomplished within medium scale equipment.

This paper will be detailed, but the purpose of this detail is to give the reader a complete picture of what inventory control entails, and to illustrate the necessity for data processing systems design to specify every significant aspect of an application.

INTRODUCTION

Inventory control quite naturally becomes a prime candidate for EDP assistance inasmuch as inventory control is very much a problem of information control and information analysis. In a business as large as the U.S. Air Force, the mountain of information involved demands not only rapid posting to ledgers for satisfying the bookkeeping requirements of the business, but also requires complex analysis for accomplishing the management function. High speed, large capacity, logically programmed data processors satisfy both these needs.

Integrated data processing, using EDP, provides the means for information aggregation and analysis for the volume of activity anticipated in a major logistical system within a time span that preserves the value of the summarizations. As implied by the term "integrated," this approach commits an organization to recognize the interdependence of the many operations in which it is engaged. Even for the manager of inventory (a small but vital facet of the total logistics picture) posting swiftly

all transactions at all of his stockage points, thus maintaining up-to-date stock balances, is not sufficient information with which to analyze his asset condition. There must be available to him back-up knowledge of system procurement status, existing program requirements, due-in balances, and outstanding obligations owed to other accounts, for it is the whole of this knowledge, plus other information, e.g. the existence and the status of interchangeable or substitute items, which makes for a true understanding of a system-wide asset position.

The EDP application discussed here is that of inventory control of the materiel supporting two major aircraft of the United States Air Force. A single point logistical support concept is in operation for these weapons. All bases flying these aircraft requisition spares from a Weapon Support Manager, who is responsible for the logistical support of these craft. Although the management is centralized, the support materiel is strategically positioned at storage sites throughout the country.

As an indication of the magnitude of this operation, the planning was geared to recordkeeping and analysis of 100,000 items, and an expected daily world-wide transaction load of 20,000 communications from bases to the Manager. The records are kept as magnetic tape files, which are scanned and processed at speeds which enable the entire 100,000 item inventory master file, for example, to be reviewed in less than two hours. The EDP for which this program was planned is the IBM 705-II.

The functions of Air Force inventory control which are part of the program to be described are: A. Input Data Control, B. Substitution and Allocation, C. Transaction Posting and Management Review, and D. Due-in and Shipment Control. The underlying difference between managing Air Force stock and managing commodities in other large businesses is in the requirement to respond to the mission of the customer. The Air Force logistician must take the 24-hour alert support demands into account in the over-all system design of an inventory control operation.

INPUT DATA CONTROL

In discussing the recordkeeping procedures and management review operations applicable to managing properly such a logistical system, we must keep in mind the need for complete knowledge by the manager for timely information relative to his system assets, repair schedules, consumption data, due-ins, etc. The data flows affecting the logistical system are between and among bases, storage sites, contractors, other Air Force depots and the Data Processing Center (DPC). In order that the DPC be capable of supporting the information requirement of the manager, all activity affecting the system, wherever it occurs, must be reported to the DPC. This is the first step in insuring that the records being kept for the manager are adjusted to reflect current status.

A system utilizing EDP, although capable of processing large masses of data with tremendous speed and accuracy, is exacting in its demands. Input data required by such a system for maintenance of records must be accurate factually and in format or the system will not produce the desired results. Such centralized management control, geared to operate with transaction information communicated from remote bases, cannot be installed overnight; it must be phased into an existing, dissimilar environment and new procedures must be learned. The problem of insuring the receipt of accurate transaction input data for processing at the manager's DPC becomes crucial, particularly at the early stage of implementation. The lack of mechanization at an input originating location generally means that transactions are either A. prepared on handwritten forms at the source for later transcription to high-speed EDP input form, or B. prepared in EDP input form at the source, where it will be an encumbrance upon the normal workload of the base.

One important aspect of Input Data Control for any EDP operation, therefore, must be data checking. Two kinds of checks must be made; one is related only to the information on a single transaction; the other is concerned with verification of the completeness of a group or batch of transactions communicated to the DPC. In both cases accuracy is the general reason for checking. In both cases the data processor itself provides the most capable instrument for accomplishing these checks.

EDITING THE INPUT TO EDP

Single transaction verification is called editing. This includes both error checking and rearrangement of data formats. One promotes accuracy, the other is necessary for processing convenience. The systems designer does not always have complete format control over all of the desired inputs to his system, but usually has the ability to recognize and rearrange data facts on transaction communications originated outside the system.

Programmed EDP error checks include:

1. Requiring the presence of given fields of information on transaction of a certain kind.
2. Range testing information fields against known upper or lower limits.
3. Validity checking, using a table of known acceptable values, all the key fields.

Batch controls, such as a transaction count, a control total, serial numbering of the transactions in a group, and the restriction of each batch to a single source organization, are necessary to insure that complete, correct transmission of transactions takes place. A centralized recordkeeping process demands that all transactions affecting centralized records be received by the DPC. The omission of transactions, or the inclusion of foreign reports results in erroneous centralized records and impairs the effectiveness of the system.

Because this input data checking is a first step in the

EDP operation, the manager of the inventory control application is assured that every required check is applied *without fail*. Routine checks are made rapidly, and judgment-type checks are programmed to the limit of the ability to state them logically. Only those exceptions which cannot be conveniently handled by EDP are manually edited. Finally, and most significantly, data errors are detected *before* they result in file garbles or undesirable logistical system reactions.

SCREENING AND DISTRIBUTING TRANSACTIONS

The screening and distribution aspect of inventory control requires a stock-number-sequenced file to be maintained for every item of supply which has ever been designated for control by the Manager. This data file is used in comparison to each incoming transaction in order to insure that the given stock number and its related data are technically correct, applicable to the manager's control system, and compatible with the records as they are currently being identified at the DPC. Furthermore, management control rules applicable to particular stock items are identified in this file, and transactions are either blocked from further processing or have management action code addended for cognizance during the processing cycle. If necessary, transactions are distributed to particular processing cycles only, or through particular functions only, or are withheld from processing until after having been thoroughly reviewed by the Manager himself.

INDEXING TRANSACTIONS

An important additional use of this file is the indexing operation. In the hundreds of thousands of items of supply in the Air Force, many items are so similar both in design and function that they are completely interchangeable. For the purpose of procurement and identification they have different stock numbers and are catalogued and stored separately. But they are managed in the inventory as a single item. The indexing process is the step necessary to identify these groups of related substitute and interchangeable items. It assures processing through the substitution and allocation function of the inventory control operation (which, it will be seen, is not necessary for any item for which no substitute possibility exists) and guarantees that any analysis of management-required statistics is done on this grouped set of parts.

SUBSTITUTION AND ALLOCATION

In any inventory control process there seems always to be the problem of critical items. These may be items that are in short supply for the known or expected needs of the system, or they may be items which have such a high value that special allocation procedures replace routine supply rules. In the Air Force there is the additional problem of assuring that materiel is available to fill requests from bases which have more urgent need by virtue of either the mission of the base, or the supply condition of the base, as compared to others of the same mission. This implies the need for a procedure for allocating spare parts which recognizes these priority factors.

THE SUBFAMILY

Since there are certain substitute relationships existing between many of the items, management of the inventory takes these into account when allocating critical items. To do this requires a data file describing the interrelationships that exist between and among the parts, and giving the useable balances of these items in the system. In addition, stock monitoring levels and rules for withdrawing stock to the limits of these levels are established for each subfamily. A subfamily is defined as a set of parts which are completely interchangeable for all applications of these parts.

STOCK MONITORING LEVELS

In our application, four stock monitoring levels have been established for the purpose of controlling issues of critical spares. In the substitution and allocation function these same levels are established for each subfamily in order to protect the entire subfamily of parts. Without subfamily levels it would be possible to fill a low priority request for Part A, of itself in sufficient supply, only to discover this part to be needed later as an interchangeable for Part B, which is in critical supply and for which a high priority request is received.

REQUIRED SUBSTITUTES

The substitution and allocation function performs an additional stock distribution control operation. The Air Force continually seeks to improve its effectiveness and operational capability and therefore supports product improvement programs which serve this purpose. Consequently, the supply system finds itself with interchangeable parts with only quality differences between them. Millions of dollars of useable inventory would be made obsolete unless some procedure could be established for purging the admittedly less desirable parts for those usages which could tolerate the lesser degree of quality. This again is a problem of allocation, and the data of the substitution and allocation file carries indicators which designate these parts as required substitutes. Requisitions for any member of the subfamily are automatically filled in the EDP operation with the stock number of the required substitute, wherever feasible. The importance of this "forced usage" of satisfactory parts has tremendous economic implications.

ACCUMULATING LOGISTICAL STATISTICS

In addition to controlling critical item issues, subfamily grouping of parts enables the accumulation of consumption, demand, and other required management statistics in a more meaningful context. Data gathered

and analyzed in this logical grouping yield requirement factors, procurement quantities and repair schedules, to mention a few management reports, which are more representative of the actual needs of the Manager. Any current asset report, submitted either regularly or whenever the stock position reaches one of the family, also includes all members of the subfamily.

TRANSACTION POSTING AND MANAGEMENT REVIEW

An inventory control process is based on a record of inventory, and a set of rules with which to effect stock movement into and out of storage locations. With EDP we are able to keep on magnetic tape balance information and management review codes for each item controlled by the Manager, consolidated into a single record which includes all the locations in the system. Thus, a complete picture of each item, regardless of its condition or its location, is available to the data processor whenever stock management rules are applied by the EDP.

THE MASTER FILE

The Master File consists of the entire set of consolidated records, one for each part. Each record carries three groups of information required either for effecting posting and review, or for processing convenience. These are Fixed Indicative Data, System Summary Data, and Location Data.

Fixed Indicative Data. Basically, this consists of catalogue-type information, such as stock number, procurement source code, dated-item codes, etc., and shipping information, such as cube, weight, unit of pack, etc. The index number, which allows the identification of subfamilies of parts, is not a part of the Air Force catalogue, but it does accompany the stock number of a consolidated record that is being managed as a member of a subfamily.

It is obvious that shipping information is needed in order to have the processor create a shipping order in answer to a requisition from a base, all management conditions being satisfied, but determination of whether or not these conditions are satisfied depends on the elements of catalogue data included in the record. Differential processing for different segmentations or categorizations of stock is a powerful technique that is routinely and consistently accomplished in EDP whenever these special characteristics are programmed for computer recognition.

System Summary Data. Within this section of each consolidated record are maintained the System Stock Monitoring Levels, which are used, in comparison with current system assets, in determining whether a system shortage or excess exists. So significant to this inventory control application is the concept of using these monitoring levels, that we shall describe this operation in detail even before a more complete discussion of transaction posting.

System Stock Monitoring Levels

Requirement Level (RL)—that level of stock (for the entire system) such that no system replenishment action is needed when system stock status is above this amount, and a routine replenishment cycle will bring stock up to the desired amount if it is initiated when system stock falls to this level.

Warning Point Level (WPL)—less than RL, indicating expected routine replenishment has been delayed. This is the first warning of impending criticality.

Allocation Level—less than WPL, indicating allocation of material to high priority needs only, while other types of requisitions are back-ordered.

Reserve Level—an amount of stock held for special release only. Coded approval of the Manager is required to draw stock below this level.

It is only by including these monitoring levels that major stock review functions of the inventory manager can be accomplished by machine. As transaction posting to the consolidated record takes place, continual stock status review takes note of the latest inventory condition within the system.

For processing convenience, System Summary Data includes totals for all conditions of materiel. Comparisons with the System Monitoring Levels is facilitated if serviceable assets held at all storage sites in the system are carried in a summary total. For this purpose the following summarizations are established:

System Summary Balances

Serviceable Summary—stock positioned at any of the storage sites of the system which is ready for issue to a using location.

Due-In Summary—stock moving into the system; these are assets soon to be available to satisfy requisitions and are included in the analysis of system asset position.

Due-Out Summary—an existing backlog of unfilled orders of all priorities.

The foregoing quantities, when compared to the System Stock Monitoring Levels, tell the Manager if the stock is at a satisfactory operating level. Defining the System Stock Status as:

System Serviceable + System Due In − System Due Out

we have a value to be compared to the monitoring levels. Before any shipping order is written by the EDP, the System Stock Status is recomputed and compared to the Stock Monitoring Levels to determine whether or not the originating requisition has high enough priority for the shipment to be affected. Furthermore, if a shipment is made, causing the System Stock Status to cross one of the Stock Monitoring Levels, a complete listing of the consolidated record for this item is produced for management attention, and a transaction is created which will later cause a listing to be made of the schedule of all materiel due into the system from outside sources. All members of the subfamily will be included in this listing.

Completing the set of information in the System Summary Data of the Master File are Reparable Summary and Work Order Summary balances which give the Man-

ager a picture of the materiel in unserviceable condition which is either available for repair or has already been scheduled into the repair cycle.

Location Data. For each of the storage sites under the control of the Manager, balances of serviceable and reparable stock and balances of items reserved for special projects are recorded and posted as transactions affecting them are processed through the EDP. A Stock Control Level is carried with each set of location data. When the Manager receives a notice of system short supply, this Stock Control Level tells him the latest computation of each storage site's desired stock position. Any replenishment is then scheduled into the sites in accordance with these levels.

TRANSACTION POSTING

We discussed the necessity for transaction reporting in a centralized recordkeeping system without indicating what kinds of transactions our inventory control operation requires. We have already stated the necessity for all reports of balance changes in the system. Implied in any EDP operation of this scope is a large file maintenance job. Transaction inputs are also required to adjust the various pieces of management data in the many files which support the separate functions of this computer application. The following list is a set of transaction types reported to the DPC that are necessary for adjusting the DPC files to correspond with reality.

Transaction Notices Which Change Balances

Inventory Adjustments
Change of Status; e.g., serviceable to reparable
Receipts
Shipping Directives
Requisitions
Reversals of Previous Balance Change Transactions

Transaction Notices Relating to File Information

Insertion of a Complete Record
Deletion of a Complete Record
Catalogue Data Changes; e.g., price, stock number
Level Changes
Requests for Information

Within each of these categories there may be several separate transactions which the processor must recognize; e.g., inventory adjustment of a serviceable balance, and inventory adjustment of a reparable balance. The detailed planning for each processing path in EDP is very exacting in its demand that *none* of these transaction possibilities be overlooked. The description which will follow will not be of the individual transactions flowing into the DPC, but rather, of the general types. The reader should extend these descriptions, especially those for file maintenance changes, in order to account for 55 separate transactions required to make this application operate.

Transaction Notices Which Change Balances

1. *Inventory Adjustment*—a revision required to bring the records in balance with the physical inventory. Reasonable tolerance limits are established within which adjustments will be accepted; otherwise management action is required to determine the cause of the imbalance. For this, and for all other balance changes, both system and location balances of the consolidated record are changed.

2. *Change of Status*—since all conditions of stock are maintained in the consolidated record, any transfer of materiel from one condition to another requires a transaction to indicate the balances affected. Frequently, serviceable materiel is withdrawn from issue until a modification is made. For the time it is undergoing modification, a suspense balance is recorded. This is accomplished by a change of status transaction.

3. *Receipts*—incoming materiel increases balances on hand and decreases due in quantities. Variations which add to the total kinds of receipt transactions are: a. items coming from contractors. b. Air Force shipments from depots, and c. trans-shipment within the system from one storage site to another.

4. *Shipping Directives*—a device for allowing management-originated shipments, either as a result of special approval procedures or as a result of urgent requisitions communicated by telephone or radio.

5. *Requisitions*—this is the primary action-originating transaction communicated to the DPC by a base. The action taken in answering requests from the bases or the repair facilities depends on a number of variables all of which must be considered with each requisition. The urgency of the demand is perhaps the most important. In the Air Force this is expressed on a requisition in terms of the mission rating of the requesting unit and the days remaining before the item can be used. But one must consider this urgency in a relative way, else stock might be issued out of turn. Of course, this is not serious if there is ample issuable stock in the system to satisfy all priorities, but is extremely serious when there is a system shortage. The total system holding, regarded in terms of the total system requirements, is therefore, another factor which must be considered when answering requisitions.

6. *Reversals*—a simple error-correcting procedure which allows for undoing EDP action which had occurred incorrectly for any reason.

Transaction Notices Relating to File Information

1. *Insertions, Deletions*—allow for the expansion or contraction of the Master File as a routine processing step concurrent with balance posting.

2. *Catalogue Data Changes*—in a centralized recordkeeping system it is imperative that the Master Files be the most current record of price, stock number, unit of issue, and every item of data required for a complete and accurate logistical computation. Recognizing that there may be time lags in bringing the many scattered base, storage site, and depot records to current status, the EDP application must be designed to change transaction information that is incorrect. This has been discussed as a part of Input Data Control, which has its file made current by Catalogue Data Change transactions.

3. *Level Changes*—as requirements for inventory change, due to variations in plans and programs, stockage objectives also must change. Especially when there is a complete and consolidated record giving the entire asset picture for the whole system, Stock Monitoring Levels should be responsive to requirements changes matched against known stockage position. Management review in transactions which update the Stock Monitoring Levels either periodically, or as a result of action taken after a short-supply condition had been noted by the EDP and communicated to the Manager.

4. *Requests for Information*—a means provided for interrogating the Files in order for the Manager to view information not available soon enough from a routine report; or, a means of providing information on an infrequent basis *in lieu of* a full periodic report.

Since report printing is the most time-consuming operation of a DPC, a Request for Information, coded to enable the EDP to extract specific pieces of information, serves the purpose of the Manager and at the same time relieves the DPC of what might be an overwhelming time burden.

Sequencing Transactions for Processing. It is important to note that the Air Force operates on a 24-hour day and that transactions are communicated with the DPC around the clock on high-speed transceiver equipment. The question then arises concerning the order in which these transactions must be processed and the frequency of processing. Although requisitions are received throughout the day, shipments to the bases are on a routine Military Air Transport Service schedule. There is obviously some period of time before the scheduled departure of these flights, and batch processing of requisition transactions is feasible. For the present, it is believed that the highest priority requisitions may be batched and processed into a shipping order with a two-hour batch cycle, while all other transactions are processed in a single 24-hour batch cycle.

The sequence of introducing transactions into the 24-hour, or major batch, cycle is of some interest. Since the files are arranged in stock number sequence, the major breakdown arranges all transactions into this order. Then, if there is more than a single input for any stock number, a further sequencing must take place. Actually, the only critical order from the balance-keeping point of view is that of placing receipt notices before requisitions and shipping directives. However, the complete rule states that all file maintenance transactions for a given stock number precede change balance transactions, and that within change balance inputs, the order is:

1. Receipts
2. Reversals
3. Inventory Adjustments
4. Status Changes
5. Shipping Directives
6. Requisitions (including previous Backorders)

Finally, for equitable stock distribution, the Requisitions and Backorders are ranked in accordance with mission-rating of the requesting unit, and the days remaining before the item can be used. Then, if allocation procedures are to be invoked, the proper distribution of stock occurs through the use of the Stock Monitoring Levels.

OUTPUTS OF MASTER FILE PROCESSING

The outputs of Master File processing are either reports or action notices. Although some of these reports are not explicitly published documents, they must be included, since the use of the Request for Information makes available timely management data on an *ad hoc* basis.

Reports

1. *The Master File*—From the point of view of the Manager, this file represents a continuous report providing him with detailed documentation of his asset position for each item in his inventory. On a regular basis; e.g., quarterly, some categories of stock will be reported completely in accordance with Air Force regulations on critical item control. On occasion, inquiry may be made to determine current stock status, which would yield a special report for management review.

2. *Transaction Register*—Each input to the EDP operation generates at least an entry onto the Daily Transaction Register. Where balances have been changed by a transaction, the new balance caused by the posting is added to the transaction before it is placed on the Register. In the case of requisitions, action coding is added to indicate the DPC action in response to the request. The Transaction Register is the audit trail provided to verify action taken within the data processor, and may be listed for visual checking when required in any number of different presentations; e.g., for each storage site location aggregated monthly and sequenced by stock number action for each day; for each stock number, a running list of daily activity within the system.

3. *System Short Supply Notices*—This output results automatically as soon as an EDP review of System Stock Status against any of the System Monitoring Levels indicates one of these systems balances has been reached. Any transaction reducing a system balance causes this review to take place, thus assuring constant surveillance of the inventory position for the Manager. It has often been said that the strict enforcement of the existing stockage review procedures would in itself be a great step towards improving Air Force inventory management. If this is the case, then an EDP application cannot help but be of benefit by providing the Manager with timely information which helps him to foresee such logistical trouble spots as System Short Supply Notices.

Action Notices

1. *Short Supply Triggers*—Mention must be made here of the interfile communication required within the DPC. Because of the capacity limitations that exist in today's data processor, the functions of inventory management have been described as separate operations, a supply and accounting function, an Input Data Control function, etc. There just are not enough information storage locations and procedure storage locations in the high-speed access memory of the IBM 705, or similar machines, for all of these functions to be performed simultaneously.

The Short Supply Trigger is therefore created within the Transaction Posting operation in order to complete the report to management which is started with a System Short Supply Notice. The Due-In File will receive the Trigger. This results in a listing of all assets expected into the system, with scheduled arrival dates, for the stock number or subfamily in short supply. With management data thus gathered and presented from any file containing data required for analysis of the shortage situation, the Manager can act judiciously.

2. *Status Notices*—If a requisition cannot be filled at the DPC, either of three actions result, any of which requires a Status Notice to be sent back to the base from which the request originated. Either a Backorder results, or a Cancellation of the requisition is effected, or the requisition is Indorsed over to an Air Force depot which holds prime responsibility for the item requested.

3. *Shipping Orders*—Perhaps the most significant action notice of the Transaction Posting and Management Review is the Shipping Order. This is a directive issued by the DPC which directs a storage site to ship a specific quantity of an item to a designated

consignee by or before a given date. The list of preferred choices of consignor had previously been made for each requisition during the Input Data Control function, but since this was done on a strictly geographical basis and without benefit of storage site balance information, the Master File now provides the means for choosing the correct shipping location.

DUE-IN

We have previously referred to reports of due-in assets. It is vital in any inventory control process to know of existing contracts for serviceable materiel, but, further, the schedule of arrival of materiel is of extreme importance. Because of production limitations, storage limitations, build-up factors in usage rates and budget considerations, deliveries to the Air Force are phased to bring certain quantities of goods into the system at a pre-determined rate. It is the purpose of the Due-In function of our inventory control operation to record and monitor the contractual obligations entered into between the Manager and suppliers. Because the Manager uses other Air Force depots as a source of supply, this is more than a procurement status monitoring. Because the vast majority of the 100,000 items in the total inventory are Air Force procured, the file size is worthy of high-speed EDP analysis. With the establishment of a Due-In File, there is the obligation to maintain the information in a current status. Since the purpose of maintaining this set of records is to be able to inform the Manager of the status of due-in serviceable assets, all transactions affecting these records must be processed against the File. The reports from this file are not usually required with any periodicity, so the processing cycle is left open. In other words, unless a management request for Due-In information occurs, there may be little need to update this file. Transactions are accumulated for an acceptable maximum number of days, and the file is updated with this batch of information at the end of this time, or sooner if an information request is made. The kinds of data needed to establish records are either of two types: A. purchase requests establish contract due-in items, or B. requisitions to a depot establish the system due-in from the Air Force. In both cases it is the original order which establishes the basic record.

Changes to this record, whether system, Air Force, or contractor originated, update the information in this file. In the main, these transactions are of the following types:

1. Receipts Notices
2. Quantity or Delivery Schedule Changes
3. Contract Amendments and Supplements

The management information published from this file is mostly in the form of status reports. The Short Supply Trigger, an output of the Transaction Posting and Management Review function, has already been described. A Request for Information, similar to that described previously, also produces a visible display of the requested due-in record. These status reports are of a special nature and would force a processing cycle to occur, at which time the report would be extracted from an updated, current file.

At regular intervals, e.g., quarterly for critical items, a Due-In Status Report is published for management review in conjunction with a listing from the Master File. The information published would include an analysis by the EDP of such things as overdue shipments, shipments arriving according to schedule, quantity variations in excess of that allowed in the contract, etc.

SUMMARY

It is important that we re-emphasize the functional approach to the whole inventory control problem. The use of EDP in the decision-making areas of this process is feasible, especially when one counts up the many, many decisions which are essentially of a clerical nature. Furthermore, if management of the Air Force (or any business) wants to be sure that policy bearing on clerical-level decisions is categorically complied with, mechanization is mandatory. A virtue of large-scale EDP is in the numbers and kinds of decisions of this type that can be spelled out within the instruction storage and file data storage capacities of this type of equipment.

But, we must hasten to repeat that our approach to this inventory control problem is predicated on the philosophy that it is not at all sufficient to employ EDP purely in clerical-level decision-making. Data analysis, using information aggregated in significant inventory terms, e.g., the subfamily, is a rewarding result from the use of EDP. In this way, policy-making is influenced by timely EDP analysis of pertinent inventory data. Stated in another way, many inventory management decisions can be formulated, the data assembled and analyzed and the decision executed in today's EDP. At the very least, the data processor is employed to bring together all the data relevant to the decision-making process for presentation to management in a comprehensive, consolidated fashion. This facilitates the Manager's decision-making process, e.g., the Short Supply Notice and the Due-In Status Report.

Finally, it must be recognized that a price is paid in automating information processing. The requirement for complete accuracy of input data, both in format and in technical contents of the input, requires rigid procedures which non-mechanized systems have been able to do without. However, editing and screening processes, as those incorporated into Input Data Control, provide inventory managers with a large measure of confidence in the validity of their files, which in the past they have been without.

Finally, a word should be said for the opportunity which the large-scale EDP provides the business systems designer for effective integration of interrelated business processes. The crux of worthwhile EDP utilization lies in good systems analysis. Hence, here is a tool for implementing methods well known to the Industrial Engineer.

The Manufacturing Progress Function

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THE importance of an improved quantitative approach to productivity is becoming more obvious as time passes. Difficulties of definition, of measurement, and of determination of causal relationships seem inevitable in any study in the area. In this paper the authors present initial empirical studies of manufacturing progress and tentative conclusions which might be helpful both in the use of the relationships described herein and in further research.

Many familiar with industrial production problems have observed that progress in production effectiveness frequently takes place as time passes and manufacturing continues. Such progress is founded upon a multitude of causes, many of which operate in any specific situation. Such progress is not learning in the true sense—improvement in the performance of a fixed task—but is essentially progress of an organization which learns to do its job better by changing the tasks of individuals. For this reason, use of the term "learning curve" is avoided, and "manufacturing progress function" used instead.

A variety of means of measuring progress are possible. Involved is the definition of methods of measurement and units of measurement that are both feasible and useful. Manufacturing accomplishment is generally measured in terms of units or volume of output, frequently as a rate of production or yield. Inputs are measured in terms of monetary cost (which is often an unsatisfactory unit due to its changing value), quantities of material, or hours of labor or machine time. For most of the studies shown here progress is measured by the relative inputs of labor hours, although studies have been made in which labor cost and total cost measures were obtained. The custom has been to measure progress against a time base, rather than against a base of cumulative production quantity. Use of total realized production is perhaps not consistent with accounting procedures, but does result in all cases studied in a considerable sharpening of the relationships developed.

One purpose of measuring progress is the desire to predict future progress for purposes of estimation, decision, planning, control, and appraisal. New product estimates, major changes in existing products, and major changes in methods of production can all be made with greater assurance if quantitative predictions of progress are available. Such progress implies varying output per employee, per work station, or per square foot and affects labor requirements, space utilization, manufacturing cost, and equipment utilization. Definition of the type of variation in quantitative terms makes possible better planning and control.

Such measures hold promise of providing a better basis for the budgeting of engineering and other efforts in cost reduction activities, for the budgeting of production vs. product engineering, and possibly for providing some objective indication of organizational achievement. Understanding of a productivity measure should be of use in decisions relating to wage policy which frequently seem to prevent such progress.

Mere knowledge of the fact that progress occurs is helpful in many decisions, but quantitative measures are essential when the amount of progress possible and likely is a significant proportion of initial or final cost. Thus, in areas where product change is rapid, the potential for significant progress generally exists and means of measuring it lead to improved decisions, different methods of manufacturing control, and greater assurance in forecasts and estimates.

WRIGHT'S MODEL OF PROGRESS

The widely used "aircraft learning curve" originated by Dr. T. P. Wright (14) represents a significant attempt to measure manufacturing progress. The resulting relationship has found broad use in the aircraft industry and in the governmental agencies which are responsible for contractual relationships and price problems in aircraft procurement. This relationship applied to other industries is studied in the paper, and its characteristics are therefore described at this point.

Dr. Wright observed that in his experience the average cost of producing each of a series of orders for a particular plane model diminished as the orders accumulated. Figure 1 illustrates this relationship. The model which Wright suggested is as follows:

$$y_i = a \cdot i^{-b}$$

where:

i is the production count, beginning with the first unit $i \geqq 1$ (usually integral values)

y_i is the labor hours required for the ith unit (alternatively can be defined as the cost of the ith unit)

a is the labor hours required for the first unit hence $a = y_1$

b is a measure of the *rate* of reduction.

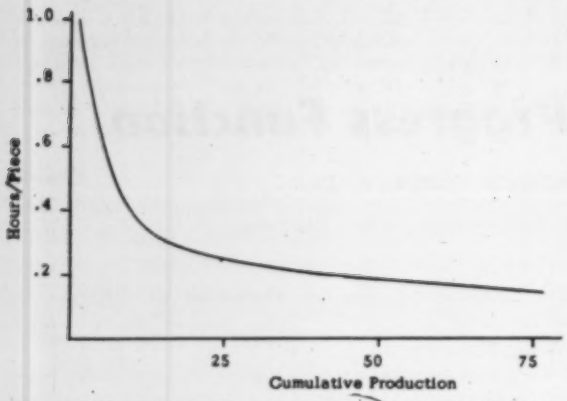

FIG. 1. 75% Progress Function on Arithmetic Coordinates.

Substituting y_1 for a:

$$y_i = y_1 \cdot i^{-b} \qquad \text{Eq. 1.}$$

This model has the characteristic of describing constant percentage reductions: each time the cumulative production is increased by a constant percentage the unit labor requirement is decreased by a constant percentage. If i_1 and i_2 are two points in production and:

$$\frac{i_2}{i_1} = C$$

then

$$\frac{y_{i_2}}{y_{i_1}} = \frac{y_1 \cdot i_2 - b}{y_1 \cdot i_1 - b} = C^{-b}$$

Hence the ratio depends only on C and b, and not on i_1, i_2 or y_1. The rate of progress is usually described by giving the complement of the reduction that occurs when the production quantity is doubled. This is equal to the quantity C^{-b} expressed as a percentage (where $i_2/i_1 = C = 2$). A "curve" for which $b = 0.322$ is designated an 80% curve ($2^{-.322} \doteq 0.80$).

The logarithmic transformation of this model is:

$$(\log y_i) = (\log y_1) - b(\log i) \qquad \text{Eq. 2.}$$

which is the equation of a straight line with slope $(-b)$. Data can be plotted in this form either by plotting the logarithms of the coordinates on conventional arithmetic coordinate paper or by plotting the data directly on logarithmic coordinate paper. Since much of the use of the progress function has been graphical it would seem likely that the popularity of this model is in part due to the convenience of the linear relationship of the log-transformed data.

The *cumulative average hours per unit*[1] is frequently considered in work with the progress function and is defined as follows:

[1] The *cumulative total* is sometimes used and is defined as:

$$\bar{y}_1 \cdot I = \sum_{i=1}^{I} y_i$$

$$\bar{y}_I = \frac{\sum_{i=1}^{I} y_i}{I}$$

where:

$\bar{y}_I$ is the average hours per unit taken over all units from the first to the Ith.[2]

Substituting for the unit time (y_i):

$$\bar{y}_I = \frac{y_1}{I} \sum_{i=1}^{I} i^{-b} \qquad \text{Eq. 3.}$$

Since this summation becomes tedious for large values of I it is convenient to approximate the sum by an integral which can be evaluated as follows:

$$\bar{y}_I \sim \frac{y_1}{I(1-b)} \left[(1 + \tfrac{1}{2})^{1-b} - (\tfrac{1}{2})^{1-b}\right]$$

The (log) plot of the cumulative average is asymptotically parallel to the (log) unit curve for the formulation given so that for large values of I (>100) the following simple relationship can be used:

$$\bar{y}_I \sim \frac{y_1}{1-b} = \frac{y_1 \cdot I^{-b}}{1-b}$$

Figure 2 shows the unit and cumulative average curves for the data of Figure 1 on logarithmic coordinates.

Some hold that the cumulative average (rather than the unit time) should be proportional to a power of the cumulative production:

$$\bar{y}_i = y_1 \cdot i^{-b} \qquad \text{Eq. 4.}$$

in which case the unit time is given by:

$$y_i = (i)\bar{y}_i - (i-1)\bar{y}_{i-1} = y_1\left[i^{-b+1} - (i-1)^{-b+1}\right]$$

which is not a linear log relationship but is asymptotically parallel to the (log) cumulative average curve. For large values of i (>20) the following simple relationship can be used:

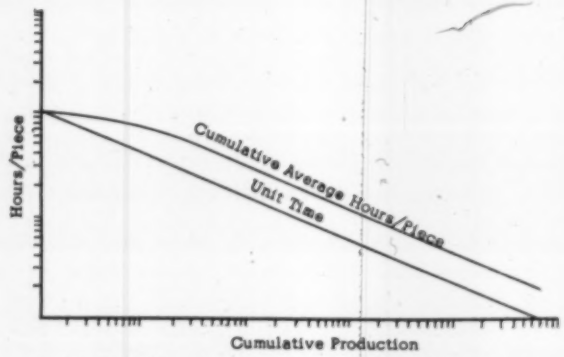

FIG. 2. 75% Progress Function with Linear Unit Curve.

[2] I is a specific value of i, used to avoid confusion when i is the index of a summation.

$$y_i \sim \hat{y}_i(1 - b) = y_1(1 - b)i^{-b}$$

Figure 3 shows the cumulative average and unit curves for the data of Figure 1 using this alternative formulation.

Since proponents of neither model are able to establish their position by logic, and empirical evidence is far from sufficient to establish the superiority of one alternative, the choice in usage has been largely a matter of computational convenience; when the unit curve is of primary interest and use, the first model is selected; when the cumulative average curve is primary, the alternative model is used. Since in either case the two curves are parallel for large quantities of production the difference is important only during the initial stages of production and hence for many applications, not crucial. The authors contend that the cumulative average formulation of the progress function is overused—primarily because the averaging process has tremendous power to smooth the data and enhance the appearance if not the substance of the curve.

It is of interest to consider the sum of two such series (assuming now the initial model):

$$y_{1i} = y_{11} \cdot i^{-b_1}$$

$$y_{2i} = y_{21} \cdot i^{-b_2}$$

The sum is:

$$(y_1 + y_2)_i = y_{11} \cdot i^{-b_1} + y_{21} \cdot i^{-b_2} \qquad \text{Eq. 5.}$$

A plot of $(y_1 + y_2)_i$ against i on log coordinates is a convex curve whose shape depends upon the four values $(y_{11}, y_{21}, b_1, b_2)$. The plot will be a straight line if and only if $b_1 = b_2 = b$:

$$(y_1 + y_2)_i = (y_{11} + y_{21}) \cdot i^{-b}$$

Therefore, if the model is assumed to hold for two separate portions of a task it cannot also be assumed to hold for their sum unless the separate curves have the same slope—which will not in general be the case. Strictly speaking then, this precludes the use of the simple "linear" model for operations, departments, sections and total of the same project. Theoretically it can at best apply to only one level.

This particular form of relationship has not yet been logically or mathematically related to manufacturing procedures in terms of quantitative cause and effect. Perhaps it never will be. The basis for its use in the aircraft industry rests upon several points. First is its intuitive logic: progress continues as production cumulates, but at a diminishing rate. It seems natural for engineers or managers first to seize those opportunities for improvement which yield the greatest progress. Thus, as production cumulates, opportunities for large savings become less obvious and are less frequently discovered. Progress continues, but more in the nature of refinements than major changes. Apparent stability is achieved, without the absoluteness of complete elimination of further progress. Second, is the fact that it fits well empirically.

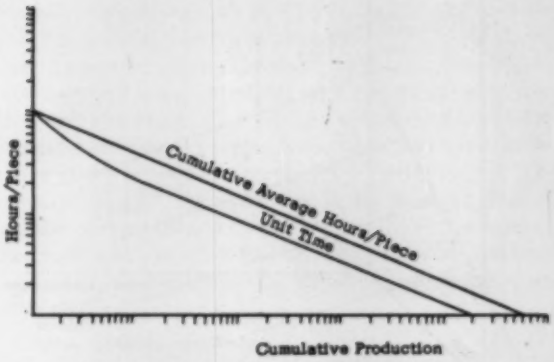

FIG. 3. 75% Progress Function with Linear Cumulative Average Curve.

Dr. Wright's original use of the form sprang from his experience (14). As can be seen from the following examples, actual production data is often well-fitted by the function.

On the other hand, Industrial Engineers have long known that once a control or quantitative objective is imposed upon an organization, there are strong forces created to make the performance fit the objective. Use of a function such as this as a control device will inevitably influence the data. Hence the argument that it has so "worked" in practice is at best a weak defense of it. It is the authors' opinion that belief in a constant percentage model such as the 80% learning curve is dangerous and is logically indefensible on an empirical basis if during the empirical period it was used as a control. There are many other questions about the manner in which the aircraft curves were derived and used, some of which are considered in reference (3).

LOGICAL RELATIONSHIPS

Presumably the cost associated with the first unit of a series and the subsequent rate of progress are the results of the engineering and production environment which bring the product into existence. Reference (8) provides a rather complete discussion of such factors divided into two categories, those activities undertaken before the initiation of production and those concurrent with production which influence cost. Presumably the devotion of more effort to pre-production factors would lower the initial cost and the devotion of more resources to during-production factors would increase the rate of cost decrease as production progresses.

The various engineering and design decisions made both with regard to the product itself and the method of manufacture are strongly influenced by the anticipated volume of production. This involves two components—the estimated rate of production and the estimated duration of production at this rate. If it is assumed that the manufacturing life of the product is expected to be relatively

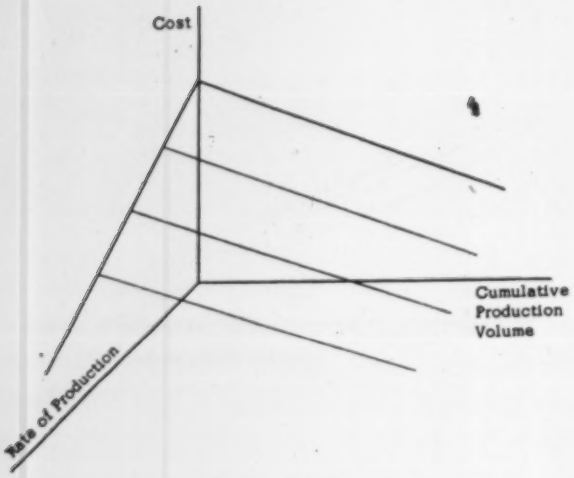

FIG. 4. Generalized Progress Function.

long, then the anticipated rate of demand becomes critical in the determination of those factors which influence cost initially. Graphically this might be illustrated by Figure 4. In general this will be a surface showing cost decreasing with an increase in either rate of production or cumulative production (and also with the third variable, not shown, anticipated duration of production). Since the progress function is an attempt to relate the reduction in cost to only one of these variables—cumulative production—the other two must be considered of primary importance in determining the characteristics of the relationship.

Among those judged important are the following pre-production factors:

1. Tooling—type of tooling used and degree of completion or development prior to production.
2. Equipment and Tool Selection—volume for which production was planned.
3. Product Design—extent to which manufacturability was considered and the degree of change required subsequently. Degree to which product design and manufacturing engineering were coordinated prior to initiation of production.
4. Methods—the degree to which work methods in detail are predesigned and the effort devoted to associated jig and fixture design, flow analysis, etc.
5. State of the Art—relationship between the difficulty of the task and the ability of the organization to perform it.
6. Magnitude of the Design Effort—time and effort devoted to the problem of pre-production manufacturing design, specifications, test, inspection, etc.
7. Shop Organization—including handling methods, pre-production training, skill, planning organization, etc.

All of these will have some bearing upon initial cost and influence the number of opportunities for cost reduction subsequently. Such subsequent progress will be influenced by a number of during-production factors of which the following are representative:

1. Tooling—changes during production, method of increasing capacity for increasing demand (replication or redesign of production method).
2. Methods—changes during production, work simplification and similar programs, operator originated changes, method of capacity increase.
3. Design Changes—degree to which manufacturing and product designs are changed to allow minor economies, specification and inspection changes as experience is gained.
4. Management—improved planning, scheduling and supervision to encourage progress, increase effectiveness, diminish delays and idle time.
5. Volume Changes—changes in rate or anticipated duration of production which affect other factors and decisions.
6. Quality Improvements—the gradual reduction of rework and repair operations, the reduction of scrap losses.
7. Incentive Pay Plans—manner in which administered, when installed.
8. Operator Learning—degree to which operators decrease time utilized in execution of a specified task.

Based on the writers' experience, the last item above has either been overemphasized or erroneously indicated as the principal causal factor in some discussions of the function (2) (9). Contrary to the opinion of many such reporters it is believed that operator learning in the true sense of performance of a fixed task is of negligible importance in most manufacturing progress. However, the operator may contribute improvements in task method in some environments. Despite this, tooling, flow, and methods changes along with product design changes have been found much more significant. Such changes are usually the result of management and engineering effort rather than operator learning in any sense.[3]

ASPECTS OF EMPIRICAL STUDIES

When these studies began in 1953, the authors could find in the literature only two studies which presumably were taken from data uninfluenced by the use of the power function as a control device. These studies were Wright's original paper which dealt with extremely low volume and parameters basically different from those in this paper, and Hirsch's study (9), from which the term progress function has been adopted. The conclusion had been reached that a number of empirical studies of data from firms with varying volumes, complexity of product, methods of engineering organization, and type of manufacture would be necessary to explore the possibility that use of such a function had any validity. In the summer of 1954, the Operations Research Office of The Johns Hopkins University made it possible to initiate some studies, and the authors had an opportunity to study the rela-

[3] It is interesting to note that most psychological studies of learning compare performance time with elapsed time rather than with accumulated number of performances. Elapsed time seems a comparatively poor measure and is certainly a difficult one to convert from one task to another as it is neither proportional to number of repetitions nor a direct measure where long cycles with interruptions are found. The authors have noticed in several studies where actual performance counts were made that a superior relationship is shown where repetitions are used as a base. See Figure 7.

tionship in a number of firms where the function was not prejudiced by previous use of any explicit progress model. Four different firms cooperated, data from eight different plants were obtained, and products ranging from extremely complex to relatively simple and in cumulative production volumes of from 50 units to 200,000,000 were studied. Subsequently, in 1955, the authors were able to complete a study of considerable depth within one organization.

RELIABILITY OF DATA

The selection of the firms and products to study is a serious problem in an investigation of this nature. The authors had had enough experience in industrial situations to believe that most firms which use individual incentives such as piece rates for wage payment and control purposes also create an environment in which output is restricted, actual labor times are seldom accurately recorded, and considerable doubt exists as to the validity of operator times charged to direct vs. indirect labor accounts. The authors therefore suffer under no delusions about the accuracy of industrial data. In addition, many accounting and cost accounting procedures also operate in such a manner that the information necessary for such studies is either unavailable in proper form or is buried in a total that includes irrelevant information such as allocated common overhead costs which may or may not vary in time. The study was approached with full knowledge of such problems, and the selection of firms and products made was on the basis of such matters as well as the desire for variety.

There are many problems in such empirical studies. Merely obtaining the production count is often difficult. Such factors as varying lot sizes, varying lead times, and varying schedules make it difficult to associate specific costs with specific production quantities of the end item. Some components will be produced in relatively large volume in initial lots, or lots will be split in process of production. In many cases, as with some standard cost systems, actual product cost in terms of dollars or labor time are unobtainable. It also is difficult to interpret design and model changes. It becomes a matter of judgment to decide when a change is significant enough to justify treatment of the product as a new model, and when it should be treated as normal progress with the current model.

PROBLEM OF AGGREGATION

Experience has shown that the problem of aggregation is a serious one. For a complete product the function applies to an aggregate of parts, components, sub-operations, and assembly operations. Or for a given organization, the function may apply to an aggregation of similar products. In any event, the function is applied to an aggregation rather than individual operations. And there exists first the problem of determining what items are to be aggregated for purposes of the investigation and then the question of the mechanics of aggregation. The selection of those items to be aggregated involves compromise between short and long range objectives since the development of a predictor and explanation of the predictor often involve two different bases of aggregation. Obviously the organization of the facility and the method of manufacture furnish one basis for aggregation while the inherent characteristics of operations performed and of the components of the product or operation furnish another. In one instance the authors used the following basis for aggregation of an electromechanical product:

1. Final assembly operations.
   a. Large labor content assembly operations, unpaced.
   b. Wiring operations.
   c. Inspection, test, clear trouble.
2. Sub-assembly operations.
   a. Major, special purpose assembly.
   b. Minor, common or standardized sub-assemblies.
3. Components.
   a. High value components.
      1—Special purpose.
      2—Common or standardized.
      3—Purchased.
   b. Low value components.
      1—Manufactured.
      2—Purchased.

The classifications shown were selected for reasons of economic feasibility, of production organization, and record organization rather than purely on the basis of content. Separation of planned or controlled or paced production situations from uncontrolled situations; of those with unlike quality characteristics; and of high labor content assembly operations which are in fact summarizations of repetitive operations from those which are summarizations of diverse operations are all highly desirable. Similar bases for segregation of parts or subassemblies can also be suggested. Such classifications, however, demand considerable competence on the part of those making the study and are subject to the criticism that for application of the function, much subjective judgment is required until more knowledge is gained.

However aggregated, problems in the mechanics of aggregation are found. Product is produced at different times in different sized lots. The question of what to add to what in order to obtain aggregated cost to associate with a specific value of cumulated production is not simple. One method is to time phase the data and add all values making up a specific accumulation of end-product. Such addition is subject to the criticism that components with long lead times actually should be associated with a later quantity of cumulated production. Another procedure is to accumulate each item cost vs. its own cumulated production and then add up values from fitted curves.

Pursuit of this latter method leads to what is an apparent logical inconsistency in use of the progress function.

As stated previously, the sum of a series of power functions is not another power function unless the powers are identical. It is certain that for various types of operations the powers or characteristics differ; hence, the attainment of a convex shape rather than a linear one will follow their addition. Implicit in this is the assumption that individual series are fitted by the function and not the aggregation. The authors well understand the logic of convexity but have no empirical data upon which to base the belief that it is the individual series rather than the aggregate that is fitted by the function. In the several situations in which the authors have considered different levels of the same product it has been uniformly true that the variability of the data varied inversely as the level of aggregation. The data for individual operations are often so highly erratic that it is largely academic to discuss whether or not the linear model is applicable. This variability diminishes as one aggregates groups of operations and ultimately includes all final assembly. There are perhaps two explanations for this phenomenon. The first is mathematical; the second is a characteristic of shop practice. First, in considering groups of operations we are in effect considering the sums of a number of chance variables. In general, such sums are much better behaved than the individual chance variables. Secondly, frequently the definition of individual operations is not constant over time. A particular portion of the work that must be performed on each unit will be shifted from one operation to another. This can be done for a number of different reasons, perhaps the most common reason being to improve the balance of operations. This means that the data for an individual operation do not represent a fixed portion of the total job. The variability of the data is inflated by having elements of work removed from or added to the task. The effect of this difficulty diminishes with aggregation; for example, considering the sum of two operations the data are unaffected by work transferred between these two operations (assuming the times for elements are additive). Considering the product as a whole, redefinition of operations does not affect the data. In either event, the error apparently lies in extreme extrapolation rather than in the area of operation described in this paper and in others using this conception (12).

REQUIREMENTS FOR ESTIMATING

The use of the device as a predictor requires some clear definition of the estimating values of the parameters of the function. Much of its use in the aircraft industry implies the use of initial cost of the first item as a basis for extrapolation and use of a uniform 80% characteristic to define slope. Even if, as seems doubtful, one is able to determine with any accuracy the cost of the first unit, its use as the basic parameter to locate the function is not necessarily advisable. As a matter of fact, in only one of the many hundreds of sets of data were the authors able to determine the first piece cost of any item, assembly, part, or component. In addition, it seems unlikely that first piece cost can be determined soon enough to enable its use as a predictor. To be useful for production decisions related to engineering effort, production planning, manpower planning, or design changes, estimates far in advance of production are necessary.

It seems logical to believe that most estimates are made on the basis of some implicit conception of stabilized production volume and conditions peculiar to the firm and its environment. This has been observed by one of the authors where a number of production engineers with backgrounds in different firms and industries estimated the cost of manufacture of the same product. The estimates varied in relation to the customs and methods of the firms involved, ranging from a maximum by an engineer from a firm that built special equipment to a minimum by an engineer from a high volume appliance producer. In one instance the authors were able to check a series of pre-production estimates with the actual production cost history of the products estimated. In this case the estimates were not achieved in general until from six months to a year after the product was in production—the time that apparently was required to allow development of the production process and sufficient volume of production to work out the bugs in production and product design and to develop an effective production procedure. In this instance the product life cycle was measured in a number of years with gradually increasing production rate which often leveled off after several years. Also, in this instance, little or no pre-production engineering took place in assembly while a great deal of pre-production engineering took place in component fabrication. Estimates seemed unbiased in either situation with perhaps more dispersion in assembly operations, but the point in time at which they were achieved differed between the two types of operation.

Apparently, study of past estimates in this manner enables an empirical determination of the relation between the average estimate and some point on the progress function. Once such a determination is made, the difficulties of obtaining first item cost are avoided. Also error in use as a predictor is minimized, since there is some possibility that control to the planned estimate may occur and opportunity for such control exists.

ESTIMATION OF SLOPE

The determination of the curve characteristic or slope is a more difficult problem. Implied is the development of classifications which differentiate properly among definable operations which have basically different cause and effect patterns. Also implied is the determination, based upon collection and analysis of sufficient data, that the function applies to the classification. Next, there is implied ability to categorize or classify a product into these classifications and finally the strongest assumption of all

—the assumption that the complex production and engineering organism will continue to act in the future as it did in the past with the result that the curve characteristics associated with each class still apply. It is this latter assumption that is most questionable, and when combined with the recognized effect of imposition of a control device there is a real danger that significant opportunities for progress may be overlooked through use of a curve characteristic that is too high.

SOME EMPIRICAL RESULTS

The following examples are drawn from the studies referred to in the introduction. The examples have been selected to illustrate certain points and to show the wide range of products to which the progress function is potentially applicable; they have not been selected as the series which are best approximated by a linear hypothesis nor are they intended to provide representative values of slope.

FINAL ASSEMBLY OF LARGE UNITS

The first example (Figure 5)[1] is the final assembly labor for an electronic assembly. The labor content could be measured in tens of hours. Fairly good estimates of the anticipated rate and duration of production of this product were available as the firm involved changes in models at regular intervals. This product superseded prior products but was similar to them, both in technology of design and general method of manufacture. The final assembly work was paced by a powered conveyor. During the early stages of production the speed of this conveyor was increased as the time required for individual operations was reduced. In such circumstances a major contributor to progress would be the rebalancing of operations. Ultimately the speed of the conveyor was stabilized and further progress could be achieved only by the elimination of operations by redesign or by improvements in quality and the consequent elimination of rework operations.

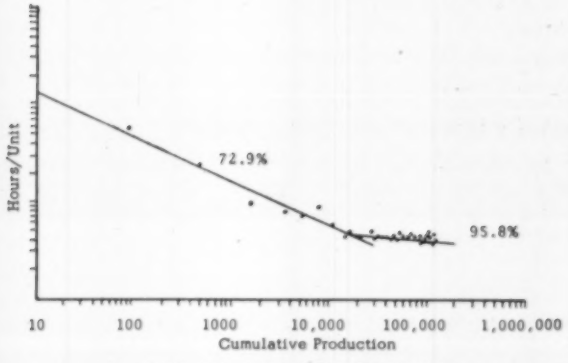

Fig. 5. Final Assembly Labor, Product A.

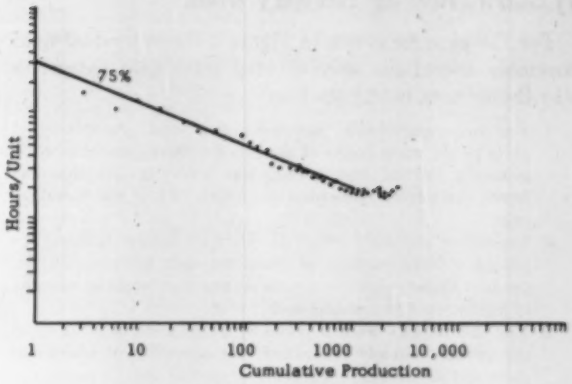

Fig. 6. Final Assembly Labor, Product B.

The final assembly for an electro-mechanical product whose labor content is in hundreds of hours is shown in Figure 6. Again in this case both the anticipated rate and duration of production could be predicted reasonably well. However, unlike the preceding example, the work here was entirely manually-paced.

The final assembly labor of a third product (not shown) of comparable magnitude and complexity exhibited a similar pattern of progress. Superficially, it would be tempting to conclude that in each of these cases the apparent convexity of the total final assembly indicates that the linear model is applicable to a lower level of aggregation. However, in the first case (Figure 5) there is a distinct change in slope, rather than a general convexity and it would seem likely that this could be attributed to the manner in which the speed of the powered conveyor was programmed. In the other two cases, progress was studied by individual final assembly operations in an attempt to answer this question as well as to identify progress characteristics with particular types of operations. It was true that in each case the individual operations exhibited considerable differences in slope, but in each case the distinct leveling out of the total final assembly at high levels of cumulative production must be attributed to the fact that certain individual operations experienced a sudden and marked reduction in the rate of progress. A most interesting observation is that this change in rate in different operations occurred almost simultaneously so that the aggregate final assembly exhibits a sudden, rather than gradual, change in slope.

[1] The data in each of the exhibits have been coded to protect the interests of the cooperating firm. No scales for the ordinates are shown; a statement of the order of magnitude of the labor content for each product is given in the text. Each point on the curves represents the mean of a lot—in no case the authors studied was every unit costed individually. The lines shown have been fitted to the logarithms of the data by the method of least squares. In that fitting each point was weighted by amount of production it represented.

CLASSIFICATION OF ASSEMBLY WORK

For the product shown in Figure 6 the individual final assembly operations were divided into three categories (by the authors, not by the firm):

1. Assembly—assembling sub-assemblies and manufactured parts to the main frame of the product. Some machine work, primarily drilling and boring, was involved, but this was minor and never represented more than 10% of the operation time.
2. Repetitive assembly—work in which a similar cycle is repeated a large number of times on each machine. In the product under consideration there was a substantial amount of highly repetitive wiring work.
3. Test and adjust—work is primarily adjustment of portions of the product already assembled; the assembly of additional parts and sub-assemblies is a minor part of the operation.

This seemed a not unreasonable classification and possessed certain empirical advantages. It coincided with organizational divisions in the firm so that data collection was simplified, and most importantly, although work was frequently transferred from operation to operation within one of these categories, rarely did work move from one category to another. The sum of the operations in each of these categories is shown in Figures 7, 8 and 9. A

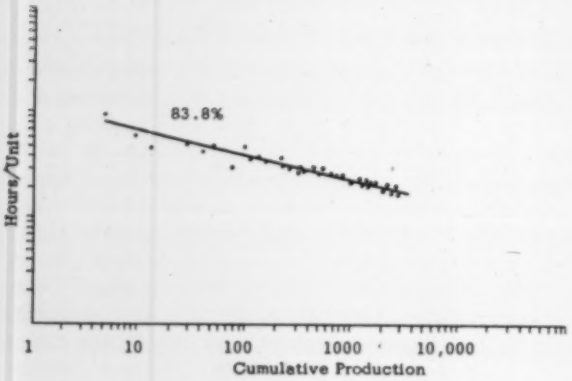

Fig. 7. Final Assembly Labor—Category 1, Product B.

distinct plateau is apparent in the plot of the "test and adjust" category, while the other two continue with approximately a constant rate of progress to the end of the data. The reason for this plateau in category 3 was never determined with any degree of certainty. Progress in this category apparently ceased when the unit time reached the time which had originally been estimated for the job. Yet progress in category 1 continued right on past the "estimated time." A special cost-reduction task force of engineers was working on this product during the first several years of its production. It is possible that this group concentrated on the test and adjust category—which initially dominated the final assembly time—until the time required was brought down to the estimated time and then turned their attention elsewhere. There is some support for this hypothesis in the record of engineering changes and tool changes but no one would acknowledge that this was in fact what had happened. Another question which has not been answered satisfactorily is whether the observed differences between categories are significant with respect to the variability of the data. Insofar as individual operations within a category could be compared, the range of slopes was not excessive although there was some overlap: the operation in category 1 with the greatest slope showed greater progress than the operation in category 3 with the least slope. However, comparison of individual operations was at best dubious because of transfer of work between operations within the same category and errors in charging time when men worked on more than on operation. The writers have not yet had an opportunity to test the hypothesis that these differences are significant on another situation; the firm with whose cooperation this study was made is currently in the process of doing so. All that can be said here is that these differences are not illogical for the types of work involved.

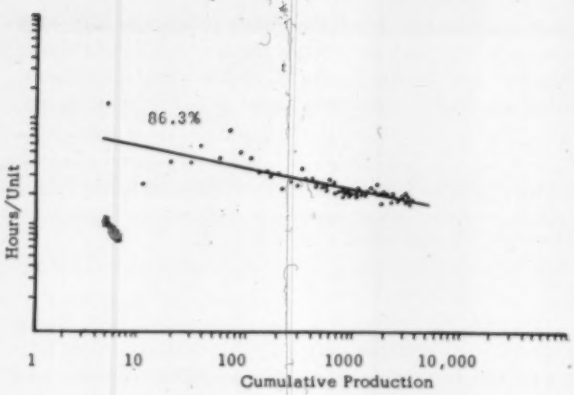

Fig. 8. Final Assembly Labor—Category 2, Product B.

EFFECT UPON AN INCENTIVE SYSTEM

In one of the two firms in which individual operations were studied an incentive wage-payment system was in

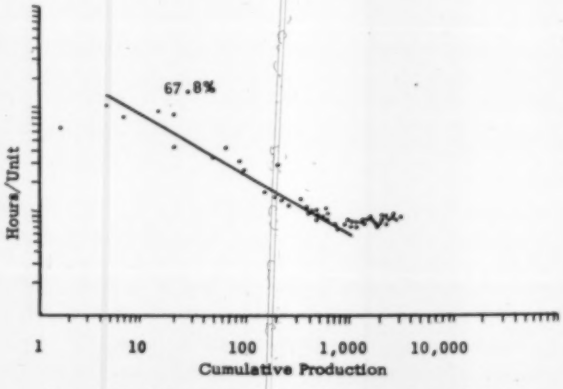

Fig. 9. Final Assembly Labor—Category 3, Product B.

use. This study provided an opportunity to observe the effect of progress on the standard-setting procedure. Considering the magnitude of the reductions in time that are apparent in any of these plots it is obvious that the standard-setting procedure must be cognizant of the existence and nature of this progress. Time-study references and instructions usually include some general warning against studying a job "before the initial difficulties have been resolved and stability achieved" but are not particularly informative as to how this stability should be detected and measured. In the present case the study of the individual operations indicated a great lack of consistency in the amount of "stability" that existed in the different operations at the time at which they were studied and there is no reason to believe that this firm is unusual in this respect. There was also evidence that strongly suggested that the "natural progress" of some operations was artificially inhibited until after the time study had taken place.

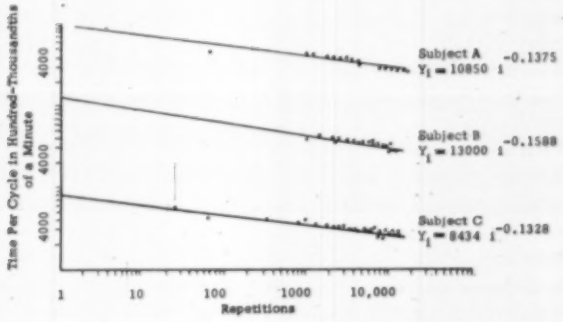

FIG. 10. Learning Curves for Subjects A, B, and C on Punch Press Operation.

WORKER LEARNING

Industrial Engineers and industrial psychologists have in a number of instances studied individual operations to measure worker learning. However, they have not been concerned with the mathematical model of progress being considered here and results have not been plotted in this manner. In one case where the basic data were reported (4) an investigator of the progress function replotted these data in an appropriate manner (8), a sample of which is shown in Figure 10.[5]

This was a study of a number of different subjects performing a punch-press operation. Figure 10 shows the "learning curves" for three of these subjects. The slopes of the (replotted) data for the six subjects tested varied between 88.9% and 91.2%. This and similar investigations are concerned with true "learning"—improvements in the performance of a fixed task, which is only one contributor to progress as that term has been used here. Moreover, there is a second consideration that is equally important. These studies are either performed in a laboratory environment or, if in an industrial environment, in a highly artificial atmosphere created by the very process of setting up a controlled experiment. The authors are convinced that the extent of the production workers' contribution to progress is as much a function of motivation and sociological factors as of physical capability. There can be considerable difference between the progress workers *will* contribute in an industrial environment and the progress they *can* achieve in a controlled experiment.

[5] Mr. Hammer was associated with the authors at the time of his work on the progress function and participated in a portion of the empirical work reported here. Figure 10 is reproduced here because of the limited availability of Reference (8).

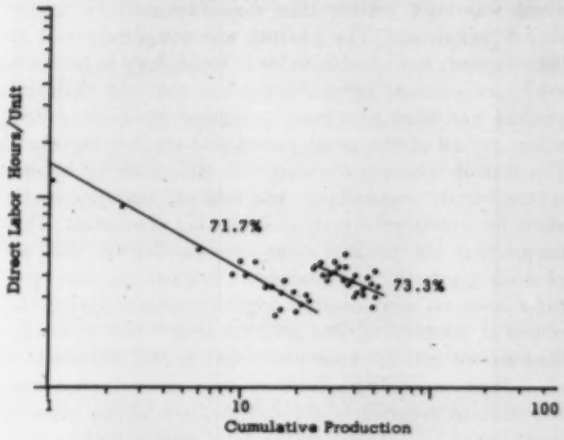

FIG. 11. Final Assembly Labor, Product D.

A COMPLEX LOW VOLUME PRODUCT

A rather unusual situation and a remarkable opportunity for study of the progress function is illustrated in Figures 11 and 12. The product concerned was a very complex, low volume (total of fifty units produced) high labor-content (measured in hundreds of hours) unit

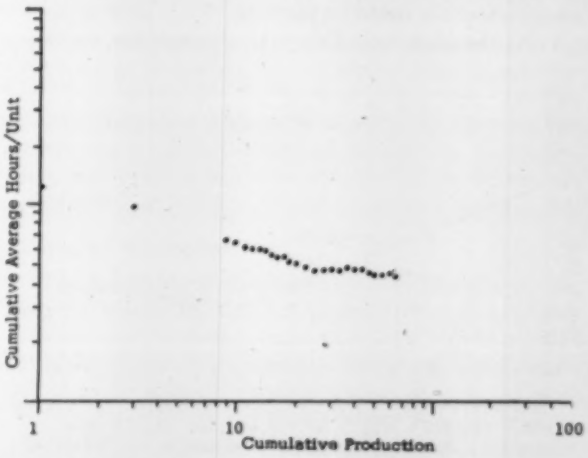

FIG. 12. Cumulative Average Final Assembly Labor, Product D.

which was built (rather than manufactured) by highly skilled technicians. The product was completely new to the company, but not dissimilar in technology to previous work. An unusual circumstance was the fact that this product had been previously produced by another firm which did all of the development and engineering work. The firm in question drew on this experience by having several of its engineers in the original manufacturer's plant for over a year prior to beginning production. This meant that the product went into production with an unusual degree of pre-production engineering and that there were no significant changes in design during the course of production. The progress shown can be attributed almost entirely to improvement in the manufacture of a fixed design, with little or none of the usual contribution to progress of the modification of the product itself over time. Moreover, the total quantity to be produced was known in advance and there was ample time to prepare tooling prior to the beginning of production. Yet in spite of these circumstances the rates of progress associated with this and a similar product of the same company were the greatest observed in the course of the study. The only explanation that can be offered is the extreme complexity of the product and the high level of skill involved in the assembly. Unlike the other products studied these were not engineered for volume production.

After the completion of the 24th unit, the entire operation was moved to another building. Many of the later units were in process at the time. The disruptive effect of the move is apparent in the plot, and the plot gives perhaps an indication of the cost of the move over and above the direct costs involved.

Figure 11 shows the labor hours required for the assembly of each unit (in some cases the average of a lot of two units). Although there is considerable variance about the line shown, considering only the portion before the move, the mean deviation is 10%; the maximum 26% —which are relatively small amounts compared to the magnitude of the reduction involved.

Using the same data, Figure 12 demonstrates the very considerable power of the cumulative average formulation to smooth out the unit data. What would be highly variable data on the unit curve with no clear linear relationship often appears quite well-behaved on the cumulative average plot and is reasonably approximated by a straight line. The appeal of this formulation is obvious but in the authors' opinion, deceptive. The cumulative average is a smoothing process whose power increases as the production quantity increases. It has somewhat the same significance as a fitted line on the unit curve; to be meaningful it must be considered with the unit curve itself. Rarely is the cumulative average hours per unit of direct interest—perhaps only when a given quantity is being produced on contract for an average price (as is often the case in airframe assembly) and even then the unit curve is of equal interest. The disadvantage of the cumulative average curve relative to a fitted line on the unit curve is that the former has a tendency to make the basic data appear "better" (in the sense of small variation) than it really is. In general one is interested in planning for and controlling current operations and the unit curve contains the appropriate and relevant information. The cumulative average formulation alone is almost useless for this purpose as for any sizeable cumulative production it becomes so insensitive to changes in the unit data that catastrophic events could take place in the job with an imperceptible effect on the cumulative average plot. It should be kept in mind that the cumulative average and unit formulations are complementary rather than competing forms; they are both derivatives of the same basic data.

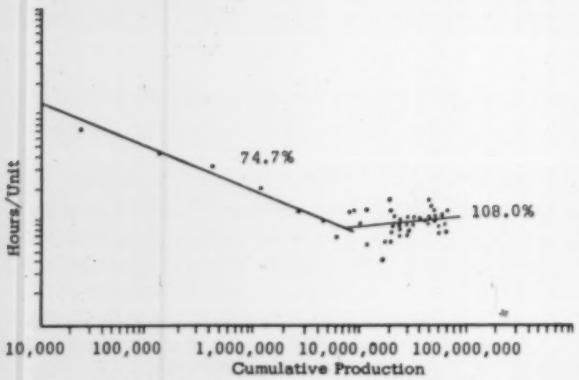

FIG. 13. Total Labor Content, Product E.

Since the volume was low and the unit cost high the units were costed individually or in lots of two units. No wage incentive system was used. This presented an unusual opportunity to obtain reliable figures on early units of production. These data suggest that the unit curve rather than the cumulative should be associated with the linear model but they are certainly not conclusive nor is it necessarily true that one alternative would be uniformly superior in all cases.

This facility also offered the rare opportunity of finding an almost ideal replication. A second product identical in volume and circumstances (the previous producer was not the same firm as for the first product) exhibited similar progress, although a slightly greater rate of progress and the same evidence of the move. The second product, however, indicates that the cumulative average formulation would be preferably associated with the linear model.

HIGH VOLUME PRODUCTION

Figures 13 and 14 represent, in many respects, an opposite situation. The figures show the total direct labor hours (assembly as well as machining) for a very small unit (labor content measured in hundredths of an hour) produced in tremendous volume (note the plot starts at 10,000 units). It was distinctly a new product for the firm

and the rate and duration of production could not be accurately predicted. The firm used a standard cost system and a wage incentive plan. To obtain Figure 13 the total direct labor cost for each month for this product (the only information available) was divided by the average hourly wage during that month to obtain a measure of the *standard* (not actual) hours used during the month. This was divided by the number of units *completed* during the month and plotted against the cumulative production as shown. This method, although certainly the easiest means of obtaining data and in some cases the only way, has the serious limitation that the data is distorted by changes in the amount of work-in-process. This causes overstatement of the rate of progress when the production is accelerating; understatement when it is decelerating; and extreme variations when the rate of production fluctuates rapidly as was the case during the latter period for the situation shown. In spite of this difficulty the curve is worth considering for two reasons. First, it shows a situation in which there is evidence of progress continuing out to a cumulative production of millions of units and this for a low labor-content product. The ultimate labor required is on the order of 15% of that for the early production. Second, because of the nature of the product and the type of work done, and the incentive payment system used, true worker learning of a fixed task can be considered to contribute only very slightly to the progress shown. Since standard hours are shown the progress results from changes in the task, either in method or in modifications of the product itself, and can be attributed almost entirely to supervisory and engineering effort. The progress results from design modifications, methods changes, introduction of tooling and automatic processing equipment. Since the labor for the month is divided by the number of units of acceptable quality a portion of the progress is due to a reduction in the number of units judged unacceptable and credit for this improvement should probably be shared with the production workers. The break in the curve can be precisely identified with the point at which the initial build-up in the rate of production stopped. Prior to this point the rate of production was constantly increasing; after this point the rate was highly variable with no period of sustained increase.

The cumulative average plot of the same data, shown in Figure 14 has the advantage in this case of being relatively unaffected by the changes in the amount of work-in-process that contribute to the variation in Figure 13.

Several similar products were studied in the same firm with similar results. In particular, the change in progress characteristic at the end of the initial production build-up was apparent and consistent.

MANUFACTURE OF COMPONENTS

In only one situation did the authors undertake to study the progress obtained in the production of the components—sub-assemblies and manufactured parts—which

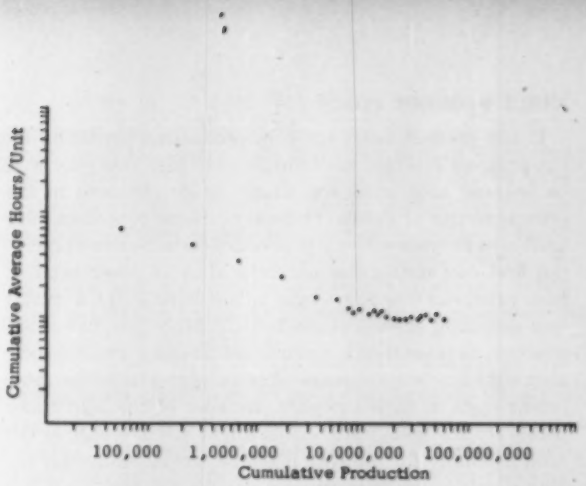

FIG. 14. Cumulative Average Total Labor Content, Product E.

are used in final assembly. Both are characterized by intermittent operation. The work is done in lots, set-up is required for each lot, and at any given moment of time only a portion of the operations are being performed. The work is usually done in multi-product departments (as opposed to final assembly in departments for one product alone) and although a machine is new and in aggregate unique, many of its parts and sub-assemblies will be similar to or identical to units of previous machines. For these reasons one would not expect as great progress on such work as on final assembly. This was the case but although the progress was not as marked as for final assembly, there were several categories—notably sub-assemblies unique to this product and high-value manufactured parts—where progress was measurable and well worth considering. In this case the only data that were available included both set-up and production time so that the unit time was sensitive to changes in lot size which took place as the rate of production increased. Making an approximate correction for set-up it was estimated that the production time was decreasing at a rate of about 90%.

Purchased parts (in this particular situation) showed no progress (measured in cost rather than hours) that could not be attributed to increasing quantities. But then this is a matter of contract between the firm and its suppliers and a contract could well be based on a mutually accepted progress function. This is done in the aircraft industry.

DOLLARS VS. HOURS

Throughout the study dollars were less predictable than hours. There were instances where the progress in labor hours was just able to keep pace with a rising hourly cost of labor so that the product cost was essentially constant. In general the best procedure seemed to be to estimate labor hours and apply dollars per hour as a multiplier to determine product cost rather than attempt to measure and predict product cost directly.

EARLY PRODUCT COSTS

If the product costs early in production predicted by the progress function are unbelievably high this may well be because such costs are almost never obtained in the normal course of events. Ordinary costing procedures are unable to provide such early product costs. For example, if the first cost obtainable occurred after 16 machines had been produced this cost would be about 40% of the initial cost assuming an 80% characteristic. Moreover, in normal practice, the cost that is given is not actually a cost associated with any one machine—it is an aggregate of the most recent costs in each category. Because of the lead times necessary for manufacture this might add the cost of the final assembly for the 16th machine; subassembly for the 20th machine, manufactured parts for the 50th, etc. For this reason alone there will be a discrepancy between figures given by progress function methods and those provided by traditional cost accounting (the difference becomes negligible for large values of cumulative production) although it is possible to adjust either figure to give a basis of comparison.

USE OF THE FUNCTION

The function has been used, or misused, in a variety of ways. It has had wide use within the aircraft industry and the Air Force as an estimating device and has furnished a basis for contract negotiation or renegotiation, facilities and manpower planning and scheduling, and even for estimating tooling requirements. See for example (3) (6) (11) (13) and (15). It has also been used as a means of pacing operators on an assembly line.

In many cases, the initial point or basis of extrapolation of the function is evidently first piece cost, or first piece estimated cost. In others it is the estimated average cost of the volume involved. In few cases is there any discussion of preparatory studies which relate the estimating procedure to some point on the curve.

Basically, the function furnishes a means of estimating labor costs in a dynamic environment. Such estimates have obvious value in such planning and decision situations as the following.

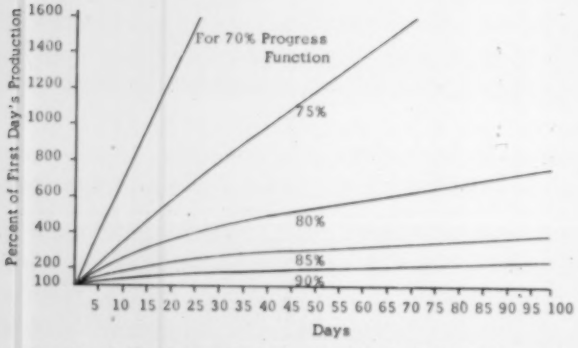

FIG. 15. Daily Output Relative to the First Day's Output Assuming Constant Labor Force.

1. Estimating costs for purposes of pricing.
2. Estimating costs of major design changes.
3. Estimating costs for purposes of make-or-buy decisions.
4. Estimating costs for comparisons among vendors.
5. Estimating labor and facility needs for planning purposes.

The obvious value of a method of quantifying and predicting progress for the planning of labor, equipment and space requirements, estimating delivery dates and scheduling raw material and component availability is apparent in the consideration of Figure 15. This figure gives the relative changes in output per unit time assuming a constant labor force for various rates of progress. Similarly a plot could be drawn of the labor force (or other productive facility) that would be required to maintain a constant rate of output, or the manner in which labor should be budgeted to achieve any desired program of production build-up.

Carrying the function into use as a detailed labor control device seems to be stretching experience too far. As previously stated, its use seems justified in situations where aggregations of operations are involved and where empirical studies have shown its applicability. Even then, there are strong underlying assumptions concerning stability of organizational, engineering, and other factors such as anticipated volume changes. Applying it to individual operations as a control is justified by no data which the authors have seen.

Where the necessary *a posteriori* studies of the estimating procedure are made, where additional empirical studies are made to determine applicability of the function and appropriate values of slope, and where there is full realization of the dangers inherent in using a device which may be upset by any of a number of changes in environment, the use of the *unit* curve appears possible.

AN ESTIMATING PROCEDURE

The following procedure is suggested as one which considers most of the pertinent aspects of the problem. It is suggested as a means of estimating the cost of a new product but can obviously be applied to major design changes in an existing product.

Begin by dividing the elements which comprise the cost of the product into logical groups according to organization lines, functions performed, or portion of the product concerned. The intent is to produce a classification of total cost into categories of similar progress characteristics. The estimating procedure will be based on estimates of the labor hours required to produce the product—the extension to cost can be made by means of average hourly rate, overhead rates as a proportion of labor cost, etc. There is undeniably a problem in projecting these rates for future times, but it would seem far preferable to separate the problems of estimating reduction in labor hours and the changes in cost per hour than to estimate the changes in total cost directly. Little has been done with the study of reduction in the material component of prod-

uct cost (except for the limited examination of purchased items aforementioned) but there is no reason why one could not quantify past experience and use it to predict reduction in material cost. Lacking such information one would probably neglect progress in this area except for obvious economies associated with quantity.

A minimum classification is to separate assembly and machining labor. Usually it is advantageous to go beyond this. Machining can be divided into parts that are unique to this machine and parts common to other machines. Parts can also be stratified according to value. Assembly work can be divided into final and sub-assembly and it will often be advantageous to further subdivide these categories according to the nature of the work being performed (such as the example given earlier). The intent is to break the labor content down into categories that have reasonably uniform behavior with regard to the rate of reduction. In general the amount of work involved in producing an estimate will increase with the number of categories used, but so will the precision and reliability of the estimate—*if* the preliminary investigation of progress experience in the firm was such as to provide the necessary information for the individual categories.

Preliminary investigation should determine what mathematical model is appropriate for each category (for the particular firm, and perhaps for a particular type of product) and appropriate values of the necessary parameters. It is obvious that the parameters will vary between categories; it is no less reasonable that models should vary between categories. For example, final assembly might be approximated by a simple power function and machining could have a model with two segments, each portion having a different exponent. A range of progress characteristics (the exponent in the case of the simple power function) should be established for each category so that a specific value can be selected depending upon such factors as the complexity and novelty (with respect to previous work) of the product and the anticipated rate of production build-up. There are more or less systematic ways of making this specification but a good deal of judgment and experience will be required in any event.

The use of the progress function does not obviate the necessity of producing an absolute estimate of the time required to do the job; the difference is only that the estimate is associated with some specific point in production. The progress function is a means of estimating what time will be required *relative to that estimate* at other points of cumulative production. In the airframe industry it is common to estimate the time for the first unit and the progress function departs from there. In other lines of manufacture the time for the first unit is neither available information nor particularly easy to estimate. Since it is not necessary to estimate the time for the first unit, it makes sense to estimate the time for whatever unit can be estimated with the smallest *percentage* error. Conventional estimating procedures are usually intended to give an estimate of the time that will be required after the operation has "settled down." It makes good sense to build upon the competence and experience of these men and procedures; however, it is necessary to associate the conventional estimate with a specific point in production. Perhaps the most satisfactory way of doing this is to try not to disturb the present estimating procedure, but to examine its past performance to determine how long it took after production began for the actual time to decrease to the vicinity of the estimate.

The estimate for each category will in general be produced in the usual way by summing the times for all of the parts or operations that are included. There are quicker and coarser ways of providing an estimate but again the matter is a compromise between the difficulty and expense of providing an estimate and the quality of estimate that is required. The detail and expense of the estimating procedure used should be consistent with the required properties of the estimate.

The individual category estimate can be conveniently obtained by tabulating multiplying factors for different points in production as percentages of the point in production for which the estimated time is given. A different set of factors is required for each different value of b. Table 1 shows slopes from 70% to 98% in increments of 2%. (In the table the unit for which the initial estimate is given is called the "Ultimate Unit"; other points in production are expressed as percentages of the production count for the ultimate unit.) An example will illustrate their use:

It is estimated that a job will require 120 hours at the 200th unit. The work is expected to experience reduction at a 78% rate. Estimate the times for the 10th, 50th, 100th, 300th and 500th units. Using the table for 78%:

Unit	*% ULT*	*F*	*F* × *Est ULT* = *Estimate*
10	5	2.927	2.927 × 120 = 351 hours
50	25	1.644	1.644 × 120 = 197 hours
100	50	1.282	1.282 × 120 = 154 hours
300	150	.8645	.8645 × 120 = 104 hours
500	250	.7202	.7202 × 120 = 86 hours

When this process has been completed for each category the time values can be extended by means of average hourly rates and burden rates to give costs which can be aggregated to give total product costs. The most satisfactory method of doing this is to specify a number of points in cumulative production and then determine the cost for each category according to the progress function at each of these points in production. Summing these values will give the total product cost at each of these points. This will give a cost for the nth machine which will not be directly comparable to accounting figures as previously discussed. However it is possible to offset the various categories according to the lead-times involved before summing the costs at the various points in production in order to produce an estimate that is consistent with and comparable to the figures that will be reported by the conventional accounting systems.

TABLE 1

Coefficients for Progress Functions with Characteristics from 70% to 98%

% ULT	70% F	72% F	74% F	76% F	78% F	80% F	82% F	84% F	86% F	88% F	90% F	92% F	94% F	96% F	98% F	% ULT
2	7.486	6.386	5.469	4.706	4.065	3.523	3.065	2.675	2.343	2.058	1.812	1.601	1.418	1.259	1.121	2
4	5.240	4.596	4.047	3.576	3.170	2.818	2.514	2.247	2.015	1.811	1.631	1.473	1.333	1.209	1.098	4
6	4.253	3.792	3.394	3.046	2.742	2.473	2.238	2.029	1.844	1.680	1.534	1.403	1.286	1.180	1.085	6
8	3.668	3.309	2.995	2.718	2.473	2.255	2.061	1.888	1.733	1.593	1.468	1.355	1.253	1.160	1.076	8
10	3.270	2.977	2.718	2.489	2.283	2.098	1.933	1.785	1.651	1.529	1.419	1.319	1.228	1.145	1.069	10
12	2.977	2.730	2.511	2.315	2.139	1.978	1.835	1.704	1.586	1.479	1.380	1.290	1.208	1.133	1.064	12
14	2.751	2.538	2.349	2.178	2.023	1.883	1.756	1.640	1.534	1.437	1.348	1.267	1.192	1.123	1.059	14
16	2.568	2.382	2.217	2.066	1.929	1.804	1.690	1.586	1.490	1.402	1.321	1.247	1.178	1.114	1.055	16
18	2.420	2.253	2.106	1.972	1.849	1.737	1.634	1.539	1.452	1.372	1.298	1.229	1.165	1.106	1.051	18
20	2.290	2.144	2.012	1.891	1.781	1.679	1.585	1.499	1.420	1.346	1.277	1.214	1.155	1.100	1.048	20
22	2.179	2.049	1.930	1.821	1.721	1.628	1.543	1.463	1.390	1.322	1.259	1.200	1.145	1.093	1.045	22
24	2.084	1.966	1.858	1.759	1.668	1.583	1.505	1.432	1.364	1.301	1.242	1.187	1.136	1.088	1.042	24
26	2.000	1.893	1.795	1.705	1.621	1.542	1.471	1.403	1.341	1.282	1.227	1.176	1.128	1.083	1.040	26
28	1.925	1.827	1.738	1.655	1.578	1.506	1.440	1.377	1.319	1.265	1.213	1.165	1.120	1.078	1.038	28
30	1.858	1.769	1.687	1.611	1.540	1.473	1.412	1.354	1.300	1.249	1.201	1.156	1.113	1.074	1.036	30
32	1.798	1.715	1.640	1.570	1.448	1.443	1.386	1.332	1.281	1.234	1.189	1.147	1.107	1.070	1.034	32
34	1.742	1.667	1.597	1.533	1.472	1.418	1.362	1.312	1.265	1.220	1.178	1.139	1.101	1.066	1.032	34
36	1.692	1.622	1.558	1.498	1.442	1.389	1.340	1.293	1.249	1.207	1.168	1.131	1.095	1.062	1.030	36
38	1.645	1.582	1.522	1.467	1.415	1.365	1.319	1.275	1.235	1.195	1.158	1.123	1.090	1.059	1.029	38
40	1.602	1.543	1.489	1.437	1.389	1.343	1.300	1.259	1.221	1.184	1.149	1.116	1.085	1.055	1.027	40
42	1.562	1.508	1.458	1.410	1.365	1.322	1.282	1.244	1.208	1.173	1.141	1.110	1.081	1.052	1.026	42
44	1.526	1.475	1.430	1.384	1.342	1.303	1.265	1.229	1.196	1.163	1.133	1.104	1.076	1.050	1.024	44
46	1.491	1.444	1.401	1.360	1.321	1.284	1.249	1.216	1.184	1.154	1.125	1.098	1.072	1.047	1.023	46
48	1.459	1.416	1.375	1.337	1.301	1.266	1.234	1.203	1.173	1.145	1.118	1.092	1.068	1.044	1.022	48
50	1.429	1.388	1.351	1.316	1.282	1.250	1.220	1.190	1.163	1.136	1.111	1.087	1.064	1.042	1.020	50
55	1.360	1.327	1.296	1.267	1.240	1.212	1.187	1.162	1.139	1.117	1.095	1.074	1.055	1.036	1.017	55
60	1.300	1.273	1.248	1.224	1.201	1.178	1.158	1.137	1.118	1.099	1.081	1.063	1.047	1.031	1.015	60
65	1.248	1.226	1.205	1.186	1.167	1.148	1.132	1.114	1.098	1.083	1.068	1.053	1.039	1.026	1.013	65
70	1.201	1.184	1.167	1.152	1.137	1.121	1.108	1.094	1.081	1.068	1.056	1.044	1.032	1.021	1.010	70
75	1.159	1.145	1.133	1.121	1.109	1.097	1.086	1.075	1.065	1.054	1.045	1.035	1.026	1.017	1.008	75
80	1.122	1.111	1.101	1.092	1.083	1.074	1.066	1.058	1.050	1.042	1.034	1.027	1.020	1.013	1.007	80
85	1.088	1.080	1.073	1.066	1.060	1.054	1.048	1.042	1.036	1.030	1.025	1.020	1.015	1.010	1.005	85
90	1.056	1.051	1.047	1.043	1.039	1.034	1.031	1.027	1.023	1.020	1.016	1.013	1.010	1.006	1.003	90
95	1.027	1.024	1.022	1.020	1.019	1.016	1.015	1.013	1.011	1.010	1.008	1.006	1.005	1.003	1.001	95
100	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	100
110	.9521	.9557	.9593	.9628	.9665	.9696	.9731	.9764	.9796	.9827	.9855	.9885	.9916	.9945	.9973	110
120	.9105	.9167	.9239	.9300	.9369	.9428	.9492	.9551	.9610	.9670	.9726	.9783	.9839	.9894	.9947	120
130	.8737	.8827	.8921	.9015	.9104	.9200	.9279	.9359	.9447	.9528	.9609	.9689	.9769	.9848	.9923	130
140	.8410	.8522	.8640	.8749	.8864	.8974	.9084	.9188	.9294	.9399	.9501	.9603	.9704	.9805	.9903	140
150	.8117	.8248	.8381	.8514	.8645	.8776	.8905	.9029	.9156	.9280	.9402	.9523	.9645	.9765	.9882	150
160	.7852	.8000	.8152	.8303	.8452	.8595	.8744	.8885	.9028	.9170	.9309	.9450	.9590	.9727	.9864	160
170	.7611	.7773	.7938	.8105	.8270	.8428	.8591	.8752	.8910	.9067	.9225	.9381	.9538	.9693	.9847	170
180	.7390	.7566	.7746	.7926	.8103	.8274	.8452	.8624	.8798	.8974	.9144	.9316	.9489	.9660	.9830	180
190	.7187	.7374	.7568	.7759	.7947	.8133	.8322	.8510	.8698	.8885	.9070	.9257	.9443	.9630	.9815	190
200	.7000	.7197	.7398	.7598	.7801	.7996	.8202	.8401	.8600	.8801	.8999	.9200	.9401	.9601	.9800	200
220	.6665	.6879	.7098	.7319	.7540	.7759	.7981	.8201	.8423	.8646	.8870	.9095	.9321	.9548	.9772	220
240	.6373	.6601	.6835	.7071	.7306	.7543	.7783	.8022	.8265	.8508	.8754	.8999	.9249	.9498	.9748	240
260	.6116	.6355	.6602	.6848	.7103	.7349	.7607	.7863	.8123	.8384	.8649	.8914	.9182	.9453	.9726	260
280	.5887	.6137	.6392	.6650	.6915	.7177	.7447	.7717	.7992	.8270	.8550	.8834	.9122	.9412	.9704	280
300	.5682	.5939	.6203	.6471	.6743	.7019	.7301	.7586	.7875	.8161	.8462	.8761	.9066	.9374	.9684	300

This aggregation can be done graphically, which is probably the most rapid method although accuracy is limited. It can be done very satisfactorily by means of tables of progress function factors and a desk calculator, or of course, it can be programmed for automatic calculation (7).

The estimates for individual categories in practice will be of greater utility than the total cost since actual costs will in general be compared to the estimate by category as well as in aggregate and if corrective action is to be taken, information broken down by categories will be invaluable. A logical extension of the work is to place control limits above and below the times estimated for each category and to institute such action only when the exceeding of these limits indicates that a significant departure from the predicted course has occurred. There is much yet to be determined about the distribution of log-transformed data and the performance of the usual statistical tests using such data but in general the results can be best interpreted by considering that they apply to percentages rather than absolute amounts. (On log-log coordinates a given distance represents a constant percentage anywhere on the plot (5).)

An important part of the estimating procedure should be a follow-up which will provide information which can be used to improve the procedure. With this in mind all of the conditions which surrounded a particular estimating job should be explicitly recorded so that when actual information becomes available the performance of the procedure can be critically reviewed.

The mechanics of applying the estimated labor hour requirement at various levels of production does not need detailing here. However, several cautions might be voiced. Inspection of the log-log plot will show that a major portion of the abscissa will amount to a very small portion of the quantity shown on the scale. Hence, the plot overemphasizes the early data. Also, error in selection of the slope parameter can be serious. Use of 75% instead of a correct value of 80% where the estimate is based on a volume of 1000 units which takes six months to produce will result in an excessive allowance for the first 1000 units or six months' production. On the other hand the function will call for a much greater reduction than is feasible for subsequent units.

CONCLUSIONS

Research on the subject of manufacturing progress so far has been fragmentary. Few or no attempts at logically constructed experimental situations have take place. Investigation has been largely limited to certain highly spe-

cialized industries. No one approaches the position of being able to see standards for progress on a universal basis. From the studies that have been made some general results of value in further study have been obtained. It seems evident that manufacturing progress is not generally learning in its true sense and further studies should attempt to differentiate this type of progress. Caution should be exercised not to utilize data obtained under conditions in which application of some conception of progress have forced results whether such application is the function described herein or another one. Great care should be take to validate output and labor consumption data. Aggregation has often been helpful in avoiding change in job content or responsibility for various operations. Use of the unit curve rather than the cumulative average curve will be found more illuminating and will provide the same amount of information. The average curve serves to dampen out variation to such an extent that major changes are obscured, and for want of objective statistical techniques it is important that the full amount of such variation be obvious. In all studies attention must be paid to changes in production rate or anticipated production rate, as such variation has been found to be important in the use of the function, especially where wide swings take place. Use of a labor hour base or a machine hour base has been found to be much more illuminating than dollar costs. Where dollar costs are desired they may be used as a multiplier, but price changes serve to mask production progress in terms of fundamental resource consumption.

Despite the various difficulties and unsolved problems mentioned, several positive conclusions may be drawn. First, progress exists—in greater degree, for longer periods of time, and for more products than would have been expected. The log-log formulation of proper data shows the duration and extent of this progress more clearly than arithmetic plots. Empirical studies also indicate that the amount of progress experienced in the industries studied is significant in both economic and planning terms and in many cases is very well fitted by the log-log plot.

Secondly, it can be concluded that there are significant differences in patterns of progress for different industries, different firms, different products, and different types of work. There is no such thing as a fundamental law of progress such as the "80% learning curve" used in the aircraft industry. No particular slope is universal, and probably there is not even a common model. The contention that such exists is most difficult to defend either logically or empirically. The virtue of a particular model has been neither proved nor disproved. Neither have particular values of slopes for various situations been determined. (Within limits this can be done for a specific firm.) The important thing to recognize is the existence of progress and the desirability and possibility of measuring progress.

Thirdly, progress can be predicted within some firms by the use of the progress function with tolerable amounts of error. In many industrial functions—notably estimation and planning manpower requirements and resultant manufacturing costs—a forecast of progress must be used. The progress function should give better estimates than any other device known to the authors. Although no basis exists as yet for selecting either the cumulative average or the unit cost as the linear function, and although the problem of convexity and its resultant errors is still unsolved, the use of the cumulative production volume as a base seems to provide an adequate estimating function for labor or facility utilization. The log-log relationship fits astonishingly well in many situations and the authors were able to develop an estimating procedure that has seemingly worked very well in practice for one sizeable firm. It should be emphasized that the basic estimating procedure of manufacturing cost need not be changed. It is merely properly phased into relation with the plant's experience in progress.

Fourthly, the authors have concluded that as a firm cumulates experience with the device (it being little more than a means of summarizing past experience) and makes intelligent observations of its use and variations which occur, it should aid in making economic decisions hitherto difficult to quantify: effect of method on design changes, timing of changes. In the long run there is hope that it can help to answer questions of organization—single or multiple product departments, allocation or organization of engineering effort and similar questions. The difficulty of isolating the many factors involved in such complex problems may make such results unlikely in the near future, but studies of the sort indicated show as much promise as any techniques presently available.

Finally, it is concluded that caution must be exerted in any application of the function to base it firmly upon empirical studies within the firm or plant where it is to be applied and upon the full realization that its application will influence the observed data. It is important therefore that the standard not be initially so loosely set as to miss potential reductions. Its application in other industries than those already studied waits further investigation. It is hoped that as additional experience with it is gained that the users will not be reluctant to divulge such experience so that all may profit thereby.

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The Compatibility of Value Engineering Analysis and Reliability

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VALUE engineering and reliability are often thought to be in conflict with each other, a belief predicated on the basis that reliable design is expensive design. Indeed, justification for this expense is obtained by demonstrating the reduction in maintenance, installation, operation and logistic costs which result from improved equipment reliability. It is my intention to demonstrate that the initial cost can sometimes be reduced by a value engineering analysis at the same time the reliability of the equipment can be improved. The compatibility of value engineering and reliability is not a dream—it is a proven fact.

Value engineering analysis can be and is a tool for improving the reliability of equipment without necessarily reducing its initial cost. The converse is also frequently found to be possible.

Before we examine how compatible reliability and value enginering actually are, it may prove beneficial to discuss what these two terms mean to us in the electronic industry.

RELIABILITY

Reliability can be defined as the probability of success or operation of particular equipment to perform its function as it was designed to do. This includes the environmental conditions under which the equipment operates, the time period the equipment is to operate and the specific functional responsibility of that equipment. Reliability studies under this definition include consideration of such items as down time, maintenance, marginal checking, modularization, human engineering, component part failure analysis, packaging, heat dissipation and a host of other items. It is therefore axiomatic that reliable equipment will have the degree of completeness required by the optimization of each and every characteristic that may affect the reliability of that equipment.

VALUE ENGINEERING ANALYSIS

"What does all this reliability cost?" is a common question heard among members of our industry and members of the military services. We are assessing these costs and value engineering analyses are being made to evaluate the function and its requirement for the expense involved. A value engineering analysis is defined as "an objective appraisal of all elements of the design, construction, procurement, installation, and maintenance of equipment, including the applicable equipment specifications, in order to achieve the necessary functions, maintainability and reliability of equipment at minimum cost" (10) (11). Thus value engineering is not simply cost reduction—it is an analysis of function versus cost.

Total cost is another way of expressing the definition. Total cost is made up of the initial or procurement; installation, operation, maintenance, logistic, replacement parts costs and the amount of time needed to install, maintain, and await the arrival of special parts not readily available. A value engineering analysis is a study of each operating function to determine its contribution to the overall worth of the equipment. Each characteristic is evaluated to optimize reliability and is reviewed to determine if modifications can be made that will substantially reduce the cost of providing that degree of operability, level of reliability, etc., which was originally thought necessary. Increased reliability is a natural by-

product of equipment simplification, a value engineering analysis goal, hence it is an indication that value engineering and reliability go hand in hand.

RELIABILITY ACHIEVEMENT

Reliability can be enhanced by many different yet specific and coordinated efforts. A few of these efforts are:

1. Reduce complexity of electronic systems.
2. Reduce the number of parts in the system.
3. Provide redundant circuits or assemblies.
4. Include standby facilities.
5. Use marginal checkout techniques.
6. Reduce maintenance time by modularization, easy location of test points, built in or wired in test apparatus.
7. Improve component life.
8. Improve use of components.
9. Standardize circuits, parts and assemblies.
10. Install environmental controls.
11. Train higher skilled maintenance personnel.
12. Schedule periodic maintenance.
13. Prepare better instructions on operation and maintenance.
14. Perform systems operation analyses.

In each of these areas costs are involved. In some initial costs will be reduced; in others such costs will increase. Where the initial cost is increased, it must be justified by reductions elsewhere or reliability is substantially improved.

RELIABILITY PROGRAM

At RCA the reliability program has been a management function these past five years. We have instituted various concepts and techniques used in the prediction, measuring and evaluating of our equipment reliability. The organization depends heavily on design reviews (1), standardized parts and circuits, and feedback of information derived from failure reports, and the analyses of the mechanisms of failure to provide more reliability in our equipment. The reliability program is an integrated function of all divisions of the corporation. All groups affecting reliability such as engineering, quality control, purchasing, standards and manufacturing are represented and participate in directing the reliability program (3). The reliability program employed at RCA has been the subject of many other papers (2) (4) (5) (8) (9) (12).

VALUE ENGINEERING PROGRAM

The value engineering program like the reliability program depends upon design review and information feedback loops. Value engineering, operating as a specific effort for little over a year at RCA, is a studied and systematic approach to cost reduction.

The approach taken by RCA is vital to the electronic industry. Second looks and redesigns cost money, take time and are psychological barriers to an engineer's effective thinking. We have in our design review program united value engineers, maintenance personnel, operators and reliability experts as well as design specialists. At the design reviews, we give the designer all the pitfalls he should avoid before he starts his design; then, after his sketches and/or models are finished, his design is reviewed to evaluate his design in relation to the function required. After the third review, accomplished after complete prototype tests, the drawings are released for the first time. In other words, the design review program helps the engineer avoid costly engineering changes and field modification kits.

These are the steps taken in the value improvement program:

1. We help everyone concerned appreciate the need for improvement.
2. We organize to do the job.
3. We set goals.
4. We develop *cost prevention* techniques and train ourselves to use them.
5. We develop *price prediction* aids as an important tool in meeting our goals.
6. We continue to improve and use our *cost reduction* techniques.

The work falls into three areas, with equal responsibility for action delegated to:

Engineering—Value Engineering—optimum simplicity and lowest cost for required performance.

Purchasing—Value Analysis—better value parts, materials, and sources.

Production—Methods Improvement—development of improved fabrication and assembly processes and values.

In our value improvement tests, which are guides to better value, the following questions are asked:

In the selection and application of parts, materials, and processes *have you*

1. Challenged specification requirements?
2. Eliminated unnecessary parts or functions?
3. Simplified the design as much as possible?
4. Made maximum use of standard items?
5. Used least costly materials?
6. Designed for lowest manufacturing cost?
7. Relaxed tolerances as much as possible?
8. Used lowest cost finishes?
9. Used company component and material specialists?
10. Fully utilized purchasing's assistance to gain suppliers "know-how?"

The following critical value improvement techniques have been developed and proven by experience:

Get *all* the *facts*.
Use the *best sources* for information.
Be *specific* and omit generalities.
Evaluate design by *comparison*.
Consider the *functions* of every part.
Make use of *specialty* products, materials, and processes.
Think creatively.
Be completely *open-minded* to new ideas.
Weigh *dollars* against each *major idea*.
Use *standard parts and materials*.
Use *company services*.
Employ your *own judgment*.

The entire program is integrated by a value engineering council made up of all working department representatives including purchasing, quality control, manu-

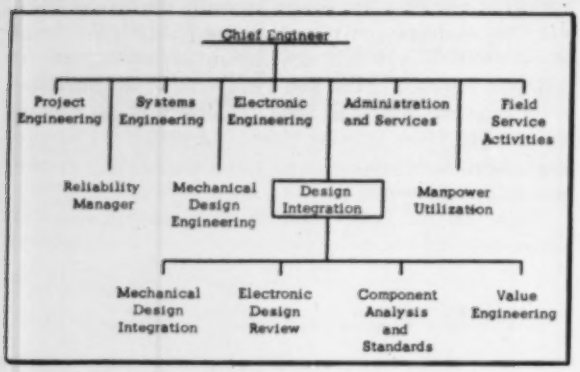

FIG. 1. Organizational Chart of Missile and Surface Radar Engineering.

facturing and engineering. Each working department has organized a team which includes responsible, decision-making personnel from those activities having cognizance over major cost elements.

ENGINEERING ORGANIZATION

An organization chart showing the major functional groups of an engineering section is shown in Figure 1.

Reliability can be improved by value engineering analyses when the analyses bring to light situations which are not to the best interest of the customer. Some of these situations may be:

1. Over designed structures.
2. Under designed structures.
3. Highly stressed components, heat, load, pressures.
4. Non-essential refinements.
5. Extra functions duplicated elsewhere.
6. Drawing inconsistencies.

COMPATIBILITY

In order to show that these two management techniques are compatible, it is felt that some specific examples would be helpful.

EXAMPLE 1: "OVER FLEXIBLE"

The initial design on a large ground radar system permitted a high degree of flexibility in the placement of the physical components of the system. Cable ducts were used throughout the design and interconnecting cables were used between the sections. The length of these cables could vary depending on the need. However, the production units of this system were subsequently decided to be for similar placement of components in each system. Each production unit was to have a building built to specifications for housing the system where this was not expected in the R&D design. Since flexibility was not needed, why were these cables required? Couldn't we use one less set of connectors and perform the same task?

The cost aspects of this example show that material (cable connectors and cable length) cost $2037.00, labor (making the connections, installation, etc.) costs $3600.00, while the new design requires $242.00 for material and $36.00 for labor. The total per unit savings amounted to $5359.00. However, certain engineering costs to make the change had to be accounted for and when these were prorated over the number of units on order, the unit savings amounted to $5030.00.

The reliability aspects are such that two soldering operations per wire and two connectors (male and female) were eliminated. The possibilities of human error in soldering and wiring and the unreliability that the connectors contributed to the circuit were eliminated. Actually there were 24 pairs or sets of connectors eliminated in each of 4 banks of connectors per system. Here is an example of value analysis contributing a major cost reduction and a substantial improvement in the reliability of the circuit.

EXAMPLE 2: IS A SUBSTITUTE AVAILABLE?

A prototype of a portable radar set we designed five years ago for the government underwent a complete value analysis by a team of design engineers, manufacturing experts, packaging engineers and field maintenance men. This analysis was performed primarily to reduce costs in order to bid on a large procurement contract.

From the analysis that reduced the overall material costs by 11%, the following three examples have been extracted for your consideration.

1. The plant was to use two Selenium rectifiers in series with each other. They were currently priced at $31.60 each. A new silicon rectifier developed within the last five years performed without a measurable difference when compared to the previous two units used. The material savings amounted to $50.80 per system. There were additional savings estimated at $3.00 per system by the elimination of mounting holes, wiring and miscellaneous hardware and assembly costs. The cost of the investigation and drawing changes amounted to $1000.00 which was prorated over the ordered quantity.

The reliability of the system was enhanced by the reduction of the number of parts used, the number of soldering joints needed, and the elimination of the ever-present human error factor in wiring.

2. A complex electro-mechanical Rectipot costing $75.00 was used as a tuning indicator. Here, our value analysis team investigated the use of a standard potentiometer available on the open market that met military specifications. It could be used with a simple gear train. The cost of the investigation, the designing and procuring the necessary gears, shafts and other hardware plus the standard potentiometer amounted to $31.00 per system. The savings, therefore, amounted to $44.00 per system. Reliability was improved by having the standard pot readily available from large production runs, which gave us a longer life, and a less unique part to replace in the field by maintenance personnel. Replacement time was reduced by having the pot more easily removed. It was smaller in size than the sealed Rectipot and could be removed with less probability of damaging adjacent components. If the gears or shafts became worn they could be more readily adjusted or replaced in the field rather than discarding the entire sealed unit. It is obvious then that greater value, lower cost, and

a higher reliability were obtained in this case.

It should be remembered that the more standard the unit, the larger the production run and therefore, the more easily the manufacturing process can be controlled. This usually results in a better quality unit with a greater stability and more reliability than the special component produced in small quantities.

3. A simple knob used to control hand rotation of the antenna of this unit was priced by our vendors at $22.00 each. After the mechanical engineering member of the team reviewed the requirements for this expensive knob he located a standard knob. The standard knob required a different size shaft and could perform the same function just as well as the special knob. The standard, oddly enough, costs only $2.20 when the cost of changing shaft sizes and appropriate drawings was added. The total savings in this case amounted to $19.80 per system.

System reliability was not altered as both knobs performed the same function. But, if the knob were broken in transit or handling, it could be replaced by a standard already stocked by the military. Thus, additional savings by the customer would accrue by eliminating one item in his logistic support centers and warehouses. By having a standard readily available, downtime is decreased and the system reliability measured in terms of system availability is improved.

EXAMPLE 3: IS THERE ANOTHER METHOD?

A large ground-based Instrumentation Tracking Radar System going into quantity production by RCA's Missile and Surface Radar department employs a boresight target for calibration purposes.

The mechanical engineer and the manufacturing methods members of the value analysis team reviewed the Engineering Model Boresight Target assembly with the express purpose of reducing its cost. The current cost of procurement is $3672.00 per assembly. As noted in Figure 2, the original design contained many castings specially fabricated for this design, a rectangular box beam and complex leveling mechanisms. The team members asked themselves—are there standard parts that will do the job? The answer of course was yes, and the complex truss work shown in Figure 2, was changed to a round aluminum pipe of a standard size and all clamps, levels and threaded castings were changed to standard commercial hardware, as seen in Figure 3.

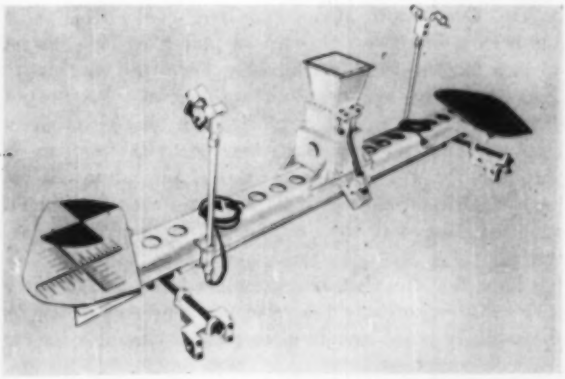

FIG. 2. Current Model of Boresight Target Assembly.

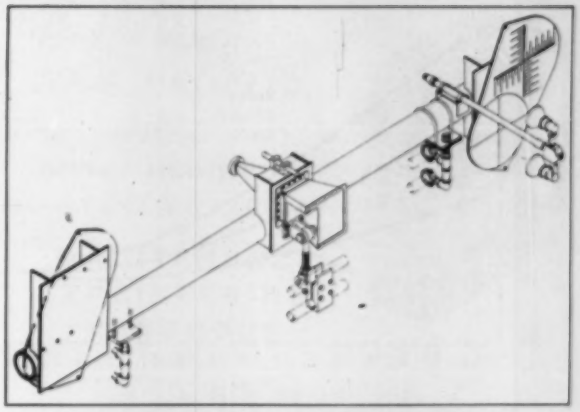

FIG. 3. New Model of Boresight Target Assembly.

The cost was reduced by $1412.00 per assembly. The reliability of the assembly was altered only in that accessibility for adjustment of the targets is more rapid. We also know that assembly quality is much higher, the availability of replacement parts is no longer a major concern of our logistics group, and installation procedure is less cumbersome and therefore more rapid.

EXAMPLE 4: ARE THE SPECIFICATIONS REALISTIC?

In some instances a value improvement analysis results in a second look at the original specifications. It may be required that to save a considerable amount of money all that is needed is another interpretation of the customer's specification. This is due to the definitions of words or phrases used in a legal document. In one particular case the specification states "that there shall be no flicker." If we chose to say there shall be no flicker at any time, the cost was estimated at $12,000.00 for an indicator and particular power supplies. However, if we chose to say there shall be no flicker 99.5% of the time, the cost of the indicator and its power supply would be about $7000.00. The function would not be impaired by a flicker only .5% of the operating time and the customer readily agreed to the modified interpretation when he saw the possible cost reduction.

EXAMPLE 5: GUIDE LINES

An analysis was undertaken to determine the ratio of vacuum tube cost to total material cost for electronic systems. Three basically different types of circuits were studied, and the costs per tube turned out to vary widely among the three groups. Costs per tube decreased for each circuit studied as the number of tubes increased; but more important, the analysis showed that regardless of system, when the number of tubes was 15 or more, the costs per tube approached the same level. See Figure 4. This technique promotes reliability as well as cost reduction by reducing the number of inter-chassis connectors, cabling, special heat dissipating ducts and blowers to

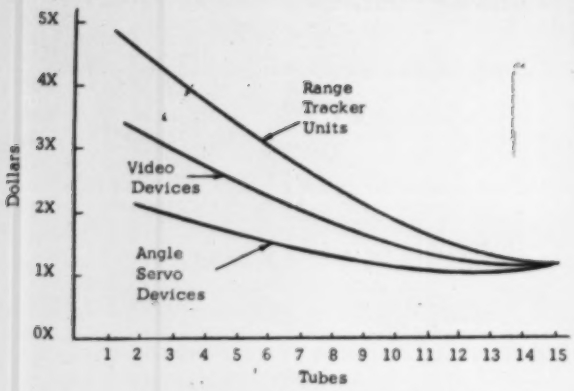

FIG. 4. Standard Material Cost vs Number of Tubes (Cost Data Coded).

remove heat from the large masses of metal, reduces the number of solder joints and allows more point to point wiring reducing the human error factor, makes circuit tracing easier, allows for more rigid construction of the chassis to withstand vibration and shock environments. The equipment may also be reduced in total weight using this technique. This cost-saving packaging method does not rule out the use of modularization, printed circuitry, or other automated manufacturing processes. These are still available, but the fewer connectors needed the better the reliability of the equipment.

EXAMPLE 6: A PLANNED PROGRAM

A complete system underwent a value improvement analysis. A program was set up with the knowledge of the basic manufacturing cost accurately based on five years of prior production on the unit. A cost reduction goal was established by marketing considerations at 20%.

The program through the efforts of the team members actually reduced costs 19.8%. The estimated cost of the analysis was $20,500.00 (estimated because some team members were not direct labor and the best estimates of the time used by these members are from their own estimates of time.) Even though $20,500.00 sounds high, each dollar spent in the program reduced the cost of the equipment by $11.40.

Due to changes in the state-of-the-art, the customer authorized a design evaluation of the equipment, so that the new unit would be more reliable, and thus more valuable to the services.

During the analysis many components were eliminated or simplified. Examples of the parts eliminated include thermistors, diodes, spacers and sleeving. Substitutions included relays, transformers and toggle switches.

These programs to improve the reliability and value-analyze the equipment are not confined to one group at RCA; it is a corporate venture. The two examples of the compatibility of value engineering and reliability shown below are an indication of what the other groups are doing in these areas.

1. The Section is producing a system consisting of 15 racks or cabinets for the military. The design engineer in the R&D stage devised his wiring for ground and RF shielding through silver-plated beryllium copper spring-finger stock. Later, in the production design, ground wiring was adopted but the spring fingers were not removed. They were retained to provide RF shielding for the cabinet. One of the mechanical engineers seeking to reduce the cost of manufacture asked why the strips were needed. He wasn't convinced that there was a need for these strips to provide RF shielding. He then obtained two completed cabinets and removed the shielding strips from one, and had RF emission tests conducted on both. There was no measurable difference in the RF emission between the units. His curiosity and persistence brought about a saving of $122.00 per system. Engineering changes to drawings etc., cost $100.00. Therefore, on the total production run of over 100 systems, a savings of over $12,100.00 was made possible.

This value analysis not only reduced costs, but reduced the maintenance required on the system. Because of their location, frequent breakage of the spring-fingers occurred and they required repair in the field, since the service man was not aware that the loss of even all fingers would not be harmful.

2. There are in this large ground equipment 16 identical electro-mechanical parts which are quite complex in nature. We were in the market for some 1700 of these parts. Suitable bids were received from component vendors. The lowest price submitted was $60.00 each.

The engineers felt that this price, although properly submitted by the vendor, was rather high for the function to be performed by the unit. Serious consideration was being given to designing this component out of the system. One engineer was sent to see the vendors that bid, to see if their manufacturing methods and/or design could be altered without affecting the function or reliability of the part. After discussing the general problem with those vendors, new bids were requested. The results showed that value improvement and value engineering can be contagious because the low vendor's final price was $25.00 under his original quotation, with no detectable difference in performance or reliability or overall configuration. The cost of the trips and the securing of new bids approximated $300.00. The total savings to the taxpayer on this one item alone will be in excess of $42,000.00.

SUMMARY

Let me stress that last phrase: "Savings to the Taxpayer." Every value engineering item cited in this paper has been realized on either a cost plus fixed fee contract or on a fixed price redeterminable downward contract.

As such, these savings do not accrue to RCA but directly to the taxpayer in the form of lowered procurement costs for the equipment ordered by the military.

Reliability was not adversely affected but rather enhanced. Delivery, availability and maintenance problems were not altered to the detriment of the purchasing activity.

I hope that the foregoing examples have demonstrated that value engineering analysis goals are compatible with the military requirements of increased reliability for the service's equipment.

It should be noted that all value engineering analyses

do not result in a cost reduction or a reliability improvement. The purpose of this paper was to indicate that value engineering and reliability are not in conflict with each other as has been generally supposed.

The value of reliability is a most important item, and is the primary characteristic that is considered in RCA's Value Improvement Program.

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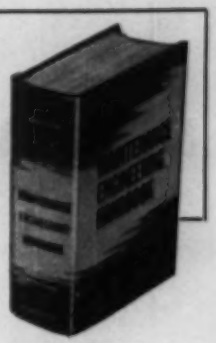

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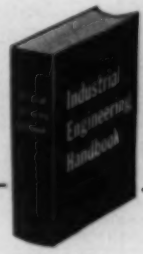

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Using Work Sampling to Study the Activities of Research Workers

by **JOHN S. HERRICK**

Chief, Management Engineering Division, Fort Detrick, Frederick, Maryland

THE type of work-measurement known as ratio-delay and originally used for determining the ratio of machine down-time to machine operation-time through the statistical analysis of a number of random observations has been found useful as a device for measuring many other types of activities. Known both as ratio-delay and work sampling, various magazines have published many articles concerning its profitable use. The intent of this article is to indicate the application of work sampling to research for the US Army at Fort Detrick, Maryland. Since the calculations and theories have been so well developed in the published articles, only passing reference will be made to them.

TASK LIST
FOR WORK DISTRIBUTION CHART

NAME:	WORKING TITLE:	MILITARY RANK OR CIVILIAN GRADE:
John Q. Doe	Pathologist	GS-9
ORGANIZATION:	**SUPERVISOR:**	**DATE:**
X Branch Research Division	Mr. Richard Q. Roe	14 January 1955

TASK NO.	DESCRIPTION	HOURS PER WEEK	"WORK COUNT" WORK UNITS AND/OR VOLUME (OPTIONAL)	POSTED ON W/D CHART TO ACTIVITY NO.
1.	Planning conference with supervisor			
2.	Planning experiments			
3.	Reading current field literature			
4.	Reading in library for background information			
5.	Preparing media			
6.	Preparing culture for inoculating			
7.	Transfer culture			
8.	Observation of experiments			
9.	Taking notes on experiments			
10.	Recording data			
11.	Calculating data			
12.	Writing reports - Monthly and special			
13.	Attending Division Seminar			
14.	Participating in Branch meetings			
15.	Discussions with other people			
16.	Getting supplies and equipment			
17.	Attending to Personnel Office requests			
18.	Assisting other members of project			
19.	Miscellaneous work			
20.	Personal time			
	TOTAL →			

FD Form 3-10
(16 Apr 1956)

FIG. 1

MANAGEMENT SURVEY

In the planning of a management survey of one research division, one of the items to be investigated was the utilization of scientific personnel. Since the investigator was an engineer and the people to be studied were biological scientists, some plane of common understanding had to be reached and a method selected that would draw forth the cooperation of the scientists. Work sampling was selected, but it was recognized that the usual approach was not possible. Before and during the application the method was continually explained to the individual scientists—stressing the application of statistics and the novelty of the application. One objection to the regular approach was the difficulty in recognizing such elements as "thinking." Another element difficult to determine was the breakpoint between necessary and unncessary experimentation. The doubt created by these elements made the analyst wonder whether there could be any clear resolution. Therefore, it was decided to select elements of work, sample the work of the scientists and research assistants, and then analyze the results without the usual statistical evaluations. A preliminary study was made to determine the existence of any relationships between personal application and scientific productivity.

Task Lists (Figure 1), as developed for Work Simplification procedures, were filled out. The blank sheets were given to the supervisors with the request that they be completed by subordinates and returned by a certain date. A few days after their completion and review by the supervisor, the completed forms were collected by the analyst. With the Task Lists at hand, the investigator, in a confidential interview with each individual, reviewed the Task Lists. Recognizing that research is definitely not a repetitive routine, the hours for the various tasks were established only as an average time. Questions were carefully posed in order to provide the analyst with the greatest possible comprehension of the duties and activities of the interviewee. This procedure necessitated training of the analyst in order that he might be able to recognize the work upon viewing it in a sampling observation.

Next, the information was transcribed from the Task Lists to the Distribution Chart (Figure 2), which summarizes the work of individuals. Following this step, a work sample sheet (Figure 3) was prepared. The information on this sheet grouped people with similar work and the same or similar mission who were working fairly close together in laboratories. Using the standard error formula,

$$\sigma_p = \sqrt{\frac{p(1-p)}{N}},$$

a round number of observations were determined. It was decided to make 40 observations a day for a period of ten working days on each of the people in the groups, one group after another until all were observed. Although considered initially, calculations as to variations were not made as the study progressed since no estimates of occurrence were available. It was felt that a general two-week work period should be used rather than attempting to bring each single work item within the limits of validity (1). After the two-week period, the developed work items were tested for validity and further study made when needed. Some 20,000 readings were taken throughout the entire division effort. Of these, only 14,443 were used as indicative of professional scientific effort; the remaining 5,557 were discarded. The discarded readings pertained to the work of supply and service personnel and the duties were not similar to those of the scientists and research assistants. The intent of the work sample application was to obtain an indication of the direction of effort of scientific personnel when their work elements were classified into the following five major categories:

1. Administration and Supervision
2. Planning
3. Execution
4. Production
5. Miscellaneous

PERSONNEL CLASSIFICATIONS

In order to avoid considerable differences in understanding of the five categories as they were used, the following definitions are given:

Administration—The management or direction of execution, application, or conduct of affairs. Administration designs the organization structure, provides for the coordination, control and final release of authority that sets the functions in action. The administrator is responsible for A. interpretation of policy, B.

ORGANIZATIONAL UNIT CHARTED: Any Project, X Branch, Research Division

WORK DISTRIBUTION CHART
(DA Pamphlet 20-300)

PREPARED BY: John S. Herrick — DATE:

☒ EXISTING ORGANIZATION ☐ RECOMMENDED ORGANIZATION

ACTIVITY NUMBER	ACTIVITY	MAN COUNT	HOURS PER WEEK	NAME: Richard Q. Roe POSITION: Spry Phlegt GRADE: GS-11 TASKS	MAN COUNT	HOURS PER WEEK	NAME: John Q. Doe POSITION: Pathologist GRADE: GS-9 TASKS	MAN COUNT	HOURS PER WEEK
1.	Administration & Supervision			Adm. Conference w/ J. Doe et al			Attend to Personnel Office request		
2.	Planning			Conf. w/Branch Chief			Confer with Dr. R. Q. Roe		
				Planning project			Reading in library for background		
				Reading			Plan experiment		
				Branch Planning			Branch planning		
				Seminar			Seminar		
3.	Execution			Conference with Associates			Conference with Associates		
				Conf w/others			Reading current field literature		
				Perform experiment			Prepare media		
				Take notes			Prepare culture for inoculating		
				Calculate data			Transfer culture		
				Attend Division Seminar			Observation and Note taking		
							Recording and calculating data		
							Assist other member of project		
4.	Production			Editing reports			Writing reports		
				Writing reports					
5.	Miscellaneous			Typing report			Getting supplies and equipment		
				Personal Time			Miscellaneous Work Leave		
							Personal Time		
	TOTALS (Manhours)								

*Each Count data is personal

ANALYSIS: WHAT TASKS THE MOST TIME?...IS THERE MISDIRECTED EFFORT?...ARE SKILLS...

PREPARED BY: DATE:

TASKS	MAN COUNT	HOURS PER WEEK	NAME: POSITION: GRADE: TASKS	MAN COUNT	HOURS PER WEEK

...IS WORK DISTRIBUTED EVENLY?

NOTE: If additional columns are required, use next required number from another block here and attach the remaining to this page.

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FIG. 2

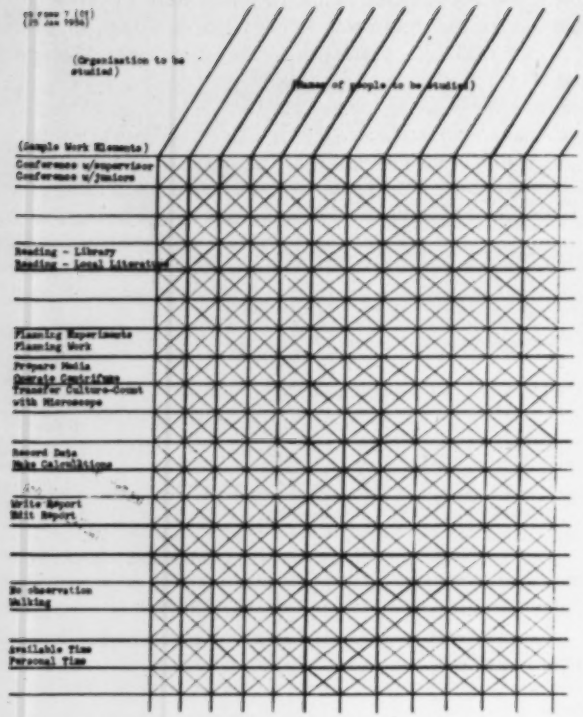

FIG. 3

removal of interferences, C. reduction of internal friction and D. stimulation and acceleration.

Supervision—The overseeing for direction or conduct, or, the direction for critical evaluation. A routine duty of supervision is integration which is an aspect of coordination. Coordination includes the design of a system for cooperation; integration is the operation of that system. Included is the adjustment of changing personalities and, when possible, the advance discovery and removal of potential sources of conflict.

Planning—A method or scheme of action prepared in advance. It is the design of the structure by which the goal is to be reached. Planning creates an orderly sequence for the accomplishment of the projects, defines the policy to be adhered to in carrying out the project, and prescribes the ultimate disposition of the results accomplished. It determines: A. the tasks to be accomplished; B. the time involved in each; C. the sequence of tasks; and D. responsibility for each.

Execution—The act or process of achieving an end. It is the follow-through to the end and the doing of what is planned. Execution performs the work and carries the experiment to the conclusion.

Production—The evolution of a product. It is the culmination of all planning, direction and control (supervision), of adherence to policies, and of reaction to assistance given in administration. Production appraises results, prepares, presents and proves the conclusion. In the division under discussion the principal indication is a report.

Miscellaneous—Those actions, often not accounted for, arising from imperfect administration which do *not* A. clearly interpret policy, B. remove all of the interferences, C. reduce all the internal friction, or D. provide adequate stimulation or acceleration. The actions may be caused by the busy supervisor who doesn't supervise, or by the incomplete plan of the planner. The actions also include the inevitable personal, fatigue and delay items which are inherent among working personnel.

DIVISION OF DUTIES

Figure 4 is an unvalued graph which expresses the theory on which the writer predicates the idea that values can be established for a standard. In the left margin are the titles of the scientists while the bottom indicates only the total availability of their effort. Since administration plays an important part in the grade and responsibility of the layers of leadership, the following definitions are given:

Division Chief—The head of an autonomous research unit carrying out a phase of the over-all program.

Branch Chief—The administrative-scientific head of an administrative and program unit carrying out one of the functions of the division.

Project Leader—The scientific head of research unit, coordinating several teams.

Section Leader—A leader who *works* on experiments in close association with other scientists.

By collecting the readings for each grade of scientist, as indicated in the left column, the work sample indicated a percentage of time that each grade spent in each of the five work categories. Due to reasons of: A. over and under supervision; B. questionable physical layout

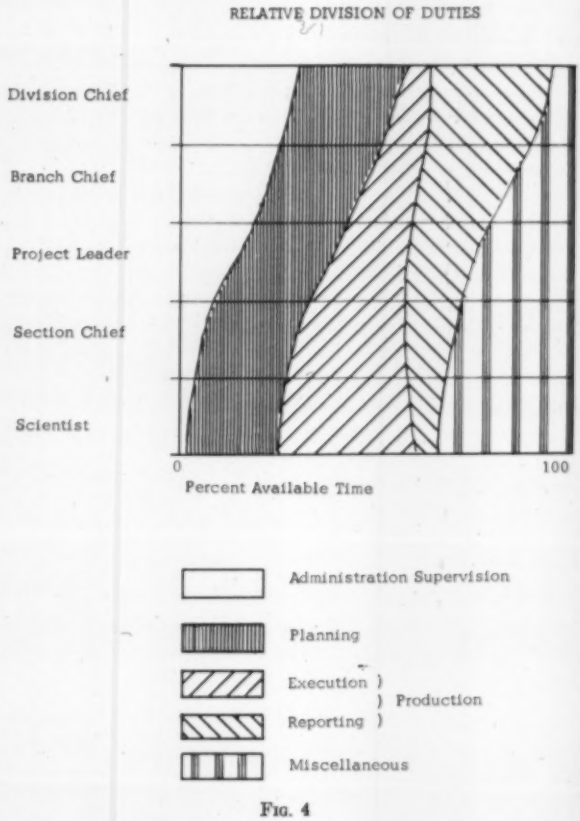

FIG. 4

of space; C. extreme variations between individuals; D. limited number of readings, etc., it was only possible to chart these percentages within wide limits. Even though these conditions had been perfect, the very nature of science depends on anthropological attributes which preclude an exact numerical definition. However, it is believed that, as more work sample information is obtained, numerical values can be determined for each layer of leadership in each of the listed categories but will be ± values.

NEEDED IMPROVEMENTS

A number of items requiring improvement were revealed as the result of observation and labor in applying the work sample. They were revealed by mere virtue of familiarity obtained by the investigator through the prior education and subsequent repeated trips in and out of the research laboratories. These needed improvements have been made.

As a result of the high percentage of elements occurring in the miscellaneous categories, the following corrective management activities have resulted or have been identified as necessary: A. procurement of additional clerical and stenographic help; B. need for additional mechanical office machines; and C. closer physical locations of work areas.

SUMMARY

The following main headings have been categorized broadly as "think" items: Administration and Supervision, Planning, Production. The remaining two, Execution and Miscellaneous, were classed as "do" items. It is obvious to the investigator that a high level of creative effort is being performed in the division, but comments elicited from members of the organization without prompting reveal that there may be insufficient "thinking" going on. These comments tend to corroborate the observed differences between the values for the "think" items in the analyst's standard (not shown here) and the same items in the work sample. Here again attention is focused on the fact that carefully detailed plans are necessary before and during any line of experimentation. Planning before experimentation establishes guidelines for the work to be carried on. Planning during experimentation recognizes changes indicated by results of experimentation.

Particular emphasis has been placed upon the "think" items since the prime product of Fort Detrick results from creative thought. It is further felt that creative thought is generated from a number of elements and does not spring forth spontaneously as a complete entity. In order that sufficient time be allotted to the generative process, emphasis should be placed on the "think" items in order to obtain the following:

1. *Recognition of the problem*—A precise sensing, which eliminates distracting influences, of the fact that a problem exists.
2. *Preparation*—The gathering of data concerning the problem; this may take the form of literature search, laboratory experiment or a conscious or subconscious rearrangement of existing data.
3. *Digestion*—Pondering over the information gathered, both in the conscious and subconscious.
4. *Creation*—Generation of new ideas or concepts occurs in this phase. Much as the reproduction of certain microorganisms is "triggered" by pricking with a pin, so the creative thought is produced. The exciting influence may be the reading of associated literature, another experiment, or even an unrelated action.
5. *Proof*—The ancient philosophers set about their proof by logic; today's science demands, in addition, more positive results in reproducible experiments.

Based on the 14,443 observations of professional scientific effort in this study, it is not possible to reach conclusions regarding the relationship between personal application and scientific productivity. Nevertheless, the more productive scientists and scientific aides were observed to apply themselves more industriously and their efforts fell into the categories expected by the analyst. It was further observed that a higher numerical job-rating grade does not particularly indicate the level of work which a scientist may be doing.

As indicated in Figure 4, it is felt that the nature of the work of the scientist changes considerably as he assumes more and more supervisory responsibility. Determination of how much of each type of work is appropriate to the grade can result only after a considerably greater number of observations have been made.

Even without the great number of observations required for establishment of numerical values, the work sample can be used as a tool in the hands of the scientific planner to determine whether or not his scientific efforts are being directed most effectively toward achievement of creative thought. Selection of appropriate work elements and use of random observations (as used in the work sample) furnish information concerning direction of effort which will enable the scientific planner to organize a more effective team.

REFERENCE

(1) "Work Sampling," *Factory*, July 1952.

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"Y'all Come"

Reader Comments

PRODUCTIVITY AND INCREASED WAGES, by Robert B. Seidel, *Journal of Industrial Engineering*, July-August, 1958.

Mr. Seidel has presented a solution to a problem with which many of us are faced. He should be commended for developing a new approach. I feel that his use of factors for developing costs other than wages have a very useful application. It would appear to me, however, that he has gone to great lengths to make a difficult problem out of a very simple one.

In the development of the factors for year "2", a sound and straightforward approach has been used, but I fail to find the purpose or need for going further. Equation 4 does give the correct solution when the appropriate factors are substituted in it, but I find it rather difficult to calculate the answer on my slide rule.

It would seem to me that a much simpler approach is to substitute the factors for year "2" in equation 2 and solve for w_2:

$w_2 = s_2 - m_2 - e_2 - f_2 - p_2$

$s_2 = Gs_1$	$s_1 = 10{,}000$	$s_2 = 10{,}500$	$w_2 = \$4{,}528$	
$w_2 = Rw_1$	$w_1 = 4{,}350$	$G = 1.05$	$w_2 = 1.041 = R$	
$m_2 = Gckm_1$	$m_1 = 2{,}850$	$c = 1.02$	w_1	
$e_2 = Le_1$	$e_1 = 1{,}000$	$k = 1.00$		
$f_2 = Kf_1$	$f_1 = 800$	$L = 1.02$		
$p_2 = Tp_1$	$p_1 = 1{,}000$	$K = 1.00$		
		$T = 1.10$		

By this method I was able to arrive at the solution quickly by using my slide rule.

Mr. Seidel indicated that it is likely that the factors G, R, L, K and T might have to be converted from a total figure to the employee basis. This is undoubtedly true in most cases and makes me wonder if it's worth the while. Why not just solve for W_2 in the first place? $W_2 = S_2 - M_2 - E_2 - F_2 - P_2$. This will give the amount of money left for wages and we can quickly determine how much we can afford to increase them, if any. Mr. Seidel says this is too cumbersome to handle. Frankly, I can't see that it is, and even if it were I know that I could at least explain it to a personnel director or a company president (the majority of whom are not engineers). Using equation 4, however, would be like trying to explain the Morse Code to my 3 year old son.

Now I must admit that many companies go about budgeting in just about the manner Mr. Seidel indicates, but I fail to see much improvement in the method he suggests. I don't believe our department heads are so naive that it will fool them any whether you ask them" How many people will you need?" or whether you ask them outright "How much money?"

If we in the Industrial Engineering field are to make any contributions to the field of Scientific Management then we should do our budgeting based on Engineered Work Standards rather than using the department head's "guesstimates." From the point of view of a "freelance" Industrial Engineer, the way to approach this whole problem is something like this:

First we estimate the anticipated sales for year "2" (some may prefer to call this the sales budget). This may be done by the sales department, but I'm not sure that we can rely on their figures. Your budget director, production control manager, Industrial Engineer, or some other department may have the information and statistics to give you a more reliable answer. Also let's make this estimate in units of sales and by product lines, or even by individual items if necessary. This way we can keep changes in prices separate from changes in volume.

Next is the most important part of the project, we calculate the direct labor hours necessary to produce the sales program. This is done by using Engineered Work Standards which have already been established for old products and using Standard Time Data for the new ones. From this calculation we know how many employees we need to meet the forecasted sales program. We can also do this for the majority of our indirect functions, such as engineering, maintenance, tool making, warehousing, and office jobs of the clerical type. Of course, in many cases our standards are much rougher for these departments and it may be necessary to rely on Mr. Seidel's method of asking the department head to estimate the number of people he will need. In all of this we will naturally take into consideration any variances which we have experienced in the past or which we anticipate will be present in the future. The only other factors in wages which we need are those which are fixed by top-management policy.

Last of all, let's use equation 1. Using factors of the nature Mr. Seidel has suggested for those factors other than wages we can substitute and solve for W_2. This gives us the total dollars available for wages. If we divide this answer by the hours required to produce the required sales we arrive at the average wage per hour we can pay. The ratio of this answer to our past experience will give us factor "R," the amount which we can increase or decrease wages. By this method we could forget about the number of employees involved and still arrive at the correct solution. If we desired we could convert the hours to a per employee basis and arrive at "R" by the average per employee in years 1 and 2 as we did previously.

The advantage of using the hour basis is that it is much simpler to divide W into two or more catagories, those which vary directly with production and those which vary in a different manner or are constant unless changed by management policy. This type of separation also makes it easier to determine "R" at several alternate sales volumes.

I have not meant to imply that we "dictatorially" tell the department heads how many employees they can have, but that we sell them that our figures based on sound engineered work measurement are correct.—*Merlin D. Schwegman, Industrial Engineer and Management Consultant, Hawthorne, California.*

AUTHOR'S COMMENTS

I appreciate your sending me the copy of Mr. Merlin D. Schwegman's critique on my recent article.

As far as an author's reply or rebuttal to Mr. Schwegman's comments is concerned, I can only say that his criticism is a sound one and that his contribution, that of engineered work standards in determining the number of employees required per department is a very worthwhile contribution and extension of this concept. I believe that it would require a rather elaborate engineering department beyond the capacity of the majority of companies to do a really scientific job of determining the number of employees required by engineered work standards and in this respect, it may be necessary to fall back on the department heads' guesstimate, as suggested in my article. This does not detract from the fact that from an objective and scientific basis, I believe Mr. Schwegman's comments and elaborations are extremely sound in theory and if one can afford the organization to accomplish it, a decided improvement in practice.—*R. B. Seidel, President, Automatic Timing & Controls, Inc., King of Prussia, Pennsylvania.*

President's Message

GEORGE H. GUSTAT

President, American Institute of Industrial Engineers, Inc.

1958-59

Human Relations in the Industrial Engineer

IN modern day thinking, the field of human relations is assuming an ever more forceful position as one of the most important attributes in every successful industrial enterprise. It ranks very high with other corporate objectives such as fine product quality, level of employment, service to customers, and certainly a sound profit structure. Let us examine some of the phases of human relations and the part that Industrial Engineers can play in implementing its future.

Stepped up research in recent years in the whole area of motivation and human reaction has uncovered several intresting developments. While many of the research scientists apparently disagree at least to some extent in their evaluation processes of human behavior, we can accept that the impact of people in any endeavor is worthy of our most careful consideration and detailed analysis. Our present day knowledge has led us to an almost universal recognition that the human relation philosophy practiced by a company and its people is a dominating force that affects all corporative objectives, be they product quality, profit motives, or the company's community standing. If we can basically accept that human relations are composed of a group of physical and social sciences, and that they are a part of every person in every company, we may visualize then that each phase of the sciences and each phase of the company must be successfully integrated for the optimum accomplishment of our corporate goals. The integration process is not in itself an easy task, and it is here that the Industrial Engineer has an outstanding opportunity for professional leadership. Our research in this field of behavioral science has enabled us to apply a series of definitions to human behavior. Likewise within reasonable degrees, we can assess priorities of achievements on various wants, urges and needs in the human being. As a further step, we know that each of these are inter-dependent as reactors and undergo a change as conditions change. That is, the accomplishment of one need may considerably increase the priority standing of another human need which in itself was previously considered of lesser importance. This ever changing array of conditions insists that our knowledge and analytical techniques be both current and flexible. As an example, simplifying of a labor operation may readily reduce the physical strain involved, but at the same time, may run the risk of introducing monotony or boredom. With this in mind, we integrate added responsibility through job enlargement, but must consider the problem of mental pressure and human capacities. In a complex field such as this of almost unlimited variables, we as Industrial Engineers must develop our course of future action. This action should plan for growth and development in the areas that will probably have the most direct impact on human relation philosophies. These can be enumerated as:

1. The coordinating factor.
2. The personal touch.
3. The company philosophy.

4. Technical and human design.
5. The education process.

As the first part of the plan of action, let's review the job we have to do in step 1, the coordinating factor. I think most of us normally regard an organization as a social system. As such, this system represents many different abilities, personalities, talents, and backgrounds. It likewise represents several different approaches in discharging assigned responsibilities. The plant manager in discharging his responsibilities, is concerned about sales volumes, the cost of operation, the industrial relations policy, the wage scales, the return to stockholders, and many others. To look at the scientist for a moment, we find that he is concerned about the scope, type and results of research and the perspective of each of his functions is far removed from the responsibility line-up of the plant manager. As opposed to these, the direct labor operator is usually concerned about getting out production with satisfactory quality, minimum waste and a good pay structure. Now to each of these people, their functioning is an important part of the whole, and each affects the total operation in one sense or another. Somewhere, somehow, the threads of necessary coordination of these various talents must be brought together. Somewhere also, the line of communications must be made effortless and effective. As technology and research advance further, the scope of any particular function will affect more and more fields of operation. It is reasonable to assume that in the design of a new process, designers, engineers, mathematicians, finance people, medical people, industrial relations, and many others would significantly contribute to the effectiveness of the process. The solution of the problem of coordination could easily be the difference between success and failure. Likewise, the communications and their translations in a common objective could readily affect the problem and its results. In the area of coordination, I believe there is one obvious and outstanding person who will be assuming the roll of bringing the threads of various talents, contributions, and objectives together. This should be the role of the Industrial Engineer. In communications where the same language is spoken in many ways, the problem is also complex. For the designer to understand the cost structure, for the mathematician to understand physical capacities, for the operator to understand the pay plan, the Industrial Engineer is the key. Of all the contributors, he alone has had the diversified education and industrial experience required, plus multi-varied contacts that are so commonplace in the life of almost every Industrial Engineer. I believe that Management will be turning more and more to this man for the answer in keeping industry effective.

Now, perhaps, we should turn our attention to another extremely important phase of human relations. This is step 2, the personal touch. The personal touch, I believe, is a prime requisite of every Industrial Engineer but is an absolute must of the successful coordinator and communicator. As we all know, we are constantly aware of an instinct that tells us we admire and respect some people above others. This instinct appears to be stimulated by several factors. But it does appear that each stimulant only exists as it conforms to what people expect. In training ourselves then to comply with what people expect, and I use the term "expect" as a general recognition of people's dignity, we must guard against the molding of superficial attitudes. I personally don't believe that there is a set pattern of training rules we can lay down for ourselves as engineers. The reason that I don't believe that this can be done is because that we would be starting with dissimilar parts—that is, our own personal make-up—and then attempting to mold each into a consistent personality. Too often we have seen the sad results of attempting to create a personality boy out of a conservative. This type of program usually ends up with an artificial air because someone is wearing a false personality. What I do believe, however, is that we can establish training objectives. These would include the merits of emotional stability, the respect for other people and their way of thinking, values of unbiased and unprejudiced actions, compliance with the accepted conventions of society and others. This in summary then, advocates that the personal touch in the engineer's attitude be developed through a philosophy or atmosphere that is centered around dealing with others. You may rest assured that we'll have many different types of people characterized as having an outstanding personality but regardless of the differences, the motives in each will be the same.

In the coordination and communication aspects previously discussed, we need this successful personal touch along with the technical ability required for outstanding accomplishments. To develop this personal touch, we must incorporate into our training objectives a realization of the value that we as engineers can have on the social order and the responsibility it carries with it. We must learn to understand ourselves and the motivating influences on those we contact. We must recognize the resistance to change as it encroaches on individual security and the fear of the unknown. We must recognize that a surface reaction may disguise some unrelated force and may be far removed from the obvious. To do this then, a program of self training and company training both in formal classrooms and in everyday affairs should be a goal. In this goal we should strive to accept people as they are and recognize and respect their particular way of thinking and acting. We should attempt to turn away from specialization and absolute go or no-go gauges of evaluating others. We should accept the responsibility that the Industrial Engineer more than any other, can develop the personal touch so needed in motivating people both on an individual basis and the team approach to problem solving.

Another phase of human relations that affects people's attitudes is step 3, the company philosophy. As many people emulate an outstanding leader, so too may we see

our people reflecting the attitude and philosophy of their own company. If we are to assume that the Industrial Engineer is to accept his responsibility as one of the key management's representatives, he must recognize the need for promoting and reflecting a sound management philosophy. In fact, I content he should take aggressive action in developing the human relation philosophy in his company. In his project studies and in various roles as coordinator, he frequently will be in a position to affect the management thinking along the human relation lines. In this respect, he must actively assess the value of a sound employee atmosphere. He must continually promote the need for the proper relationship of men, materials, and machines, and he must be one of the leaders in communicating a management attitude of acceptance toward the employee and his part in the industrial order. This is not intended as a plea for give-away programs, but rather a recognition of the fact that management philosophies do affect all company people and that these same people affect the degree of their company's success. To solicit the cooperation, operation effort and acceptance by people of new techniques or changes, it is necessary that they feel informed as to what is going on and how it affects them in their future. The manner of informing is critical because it requires sincerity, ethical honesty and straight forward factual information. Using evasiveness or a patting on the head attitude or other evidences of paternalism gives promise of being fatal if used as the reflection of a sound management philosophy. In this area of reflecting company attitude, we should be well aware of the evaluation process being made by others on all our project contacts. But in the final analysis, the evaluation is being made by management itself. It is squarely up to us to determine our capability in speaking for our company philosophy. The opportunity is ours, the measuring of our performances is still to be made.

Another part of the company attitude that the engineer can positively effect has to do with the company's reputation as an asset to the community. I realize this encompasses a whole field that contains a multitude of items and I can list only a few. But when we think of participating in community education in training, civic, social and health affairs, educational grants, planned and aggressive programs of leveled employment, programs for youth education and retirement for the aged, we can visualize the problem of assessing value, obligation and cost. Perhaps all of these cannot, and should not be construed as outside functions of the Industrial Engineer. What is important, though, is that the need for such items be considered by the appropriate agency and evaluated for decision by the proper authorities. The engineer with his particular type of experience and diversified training, is in an excellent position to contribute a great deal to the progress of the community in which he lives, the development of educational plans, the economic soundness of civic affairs and many others. Any or all of these can create a beneficial reaction in the promotion of the company's standing in the community. We should consider the value of lending our talents and training to the community progress in that we benefit those around us, our company indirectly and surely ourselves in the profession of engineering.

Turning to the technical aspects of our job, we find one of our greatest challenges in step 4 of our human relation reflections, and this is in the area, technical and human designs. In the scope of designing entire processes, specific operations, or just a particular tool, the human aspect should be the forte of the Industrial Engineer. We are living in a cycle of time where we have been a charter member in the evolution and progress of automation. On a first hand basis, we have learned of the paramount force represented by the human factor consideration in the automation growth. We have likewise learned that we are in an area where human capacity has definite limitations and can easily be the restricting factor. We do have, however, an ever increasing knowledge of degrees of reaction to responsibilities, mental pressure dangers, and the safety hazards of job boredom and monotony. Data is available on the effect of light, noise, vibration, humidity, and others. Each of these requires a step up in our engineering know-how as to design and integrated flow, not only for the process, but also for the man. We are faced with the prospect of applying consistent data in some processes, and developing individual human specifications in others. All of our previous training in planning an optimum process considering all aspects of a problem, plus the good engineering judgment that we use daily should now stand us in good stead. These along with the continued findings of the research and medical analyst in human behavior, represent some of the best guides in improving our knowledge of the man-machine process. The valid interpretation of what is the true problem in this dual integration will present a real challenge to the Industrial Engineer. The fatigue factor, long an arbituary allowance, now gives promise of becoming a piece of data that can be analyzed, computed and correctly established in almost every work situation. The work of the scientist in evaluating human ability and response to both the direct and indirect senses will enable the engineer to visualize plans and design that may easily dwarf our previous efforts. All in all, the task of truly effective man-machine flow integration is complex, but certainly not impossible. Probably, it will become even more complex, especially if technology outstrips the progress of our present knowledge, and today this gives indications of being the pattern. Yet, the model of man-machine must be done and we know that it will be. It is not mere coincidence that we find this newly created gap admirably suited to the talents of Industrial Engineers. However, the most important fact is that the challenge and opportunity in the technical and human design are growing. At this point it is strictly up to us to see how

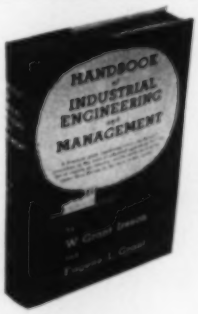
adequately we can respond and fill the bill.

The last point in our discussion of human relations is concerned with step 5, the education process. When we speak of an education process, we are not only concerned with the principles of teaching and educating others, but probably more important, educating ourselves. Ours is a profession, remember, that only a short time ago, perhaps even yet, was accused by some of narrow specialization and efficiency at all costs. Some of this criticism may have been warranted; however, today with the rapid advancement of technology and its resultant problems, we have been challenged to accept a new role in the engineering profession. How well we meet these new standards will depend to a great deal on our attitude toward assimulating all sorts of knowledge in this human relations area. We must learn to understand production operators and their natural resistance to a fast changing cycle that demands new techniques. We must learn to cope with the thinking of the scientists, the objectives of the designer, the wonderment of psychologists. In a reasonably short period of time, we can assume that each of these along with others will be fundamental contributors to the human analysis in operations and machines. A sense of project balance and an appreciation for all group members and the value of their contributions will necessarily have to be made by one of these contributing forces. Again, if we look impartially for that background that offers engineering, design, economics, human relations, and principles of leadership, we must seriously consider the Industrial Engineer. In my opinion, the people of this Industrial Engineering profession have this opportunity, not only because it is available to them, but even more, will probably be demanded of them. The education process of course, is also the keeping abreast of the scientific advances in the field of human motivations, physical standards, and psychological reactions. Text books, progress reports, and a multitude of standard data are available for studying. Many of the leading companies today are carrying out their own experimental programs in these areas as related to their own processes. In many cases, these programs have been sparked by the Industrial Engineer. Our problem today is absorbing into our own personal philosophies an understanding and need for such education and setting out to acquire its teachings. This is going to take time, study, and hard work. Rest assured however, that our role in future progress will require such diversity in our training, if we would gain the acceptance we seek.

In summary, let me state that the challenges and opportunities ahead for the Industrial Engineer are probably as great or greater today than at any other time in the history of the profession. A great amount of his ability to fulfill his challenge will depend on his knowledge to understand, evaluate, motivate and design for his fellow humans. In these respects, he will be faced with the momentous task of coordination and communications represented by many fields of endeavor. His personal touch and personnel dealings will constantly be under the scrutiny of others. His promotional attempts in developing his company's philosophy of human relations atmosphere will be difficult of achievement. His problem of visualizing and understanding the design and integration of machines with men will be beset with problems heretofore unknown. The task of enlarging his own educational processes and also that of others in the industrial and social world ahead will add tremendous amounts of time and energy requirements to an already well-burdened schedule. But realizing all of this, we have only to analyze the problem in front of us. In doing so, we will find the answer to be the Industrial Engineer. The opportunity exists, the challenge is evident, the time is now. The accepting and fulfillment are both entirely up to you.

HANDBOOK

Industrial Engineering AND Management



Edited by W. G. Ireson and E. L. Grant

A complete reference book for the industrial engineer, manager, businessman and student on the fields of activity commonly considered to be part of industrial engineering. There are 17 sections in all. Each section is complete in itself and is written by an outstanding authority in the field.

Cross-referenced and fully illustrated, there are sections on: structure of business organization, managerial economics, engineering economy, manpower management, motion and time study, factory systems and procedures, industrial climatology, tool engineering, industrial safety, inspection and quality control, and many others.

1208 pages **6" x 9", double col.** ***$16.00***

Order from:

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225 North Ave., N. W.
Atlanta 13, Georgia

CONFERENCE AND CONVENTION

The Tenth Annual National Conference and Convention of AIIE will be held:

Atlanta, Georgia

Hotel Biltmore

May 14, 15, and 16, 1959

"Y'all Come"

institute interests

PROFESSIONAL RELATIONS ACTIVITIES

The Engineering Manpower Commission of the Engineers Joint Council, since its organization in 1950, has become one of the most active of the EJC organizations and one whose objectives are of significance to all engineers but especially to the young engineering graduate. The membership in the EMC is limited to representatives of the member and associate member societies of EJC. The AIIE was elected to representation in 1956. Herbert Ashcroft, Works Manager, Bausch and Lomb Optical Company, Rochester, New York, is the Chief AIIE Delegate.

EMC Responsibilities

The EMC responsibilities are far reaching; it is charged with developing policies and procedures that will aid in:

a. Establishing the importance of engineers to our national well being.
b. Promoting the most effective utilization of engineers in maintaining the national health, safety and interest.
c. Maintaining the supply of trained engineers.

Each year the Commission prepares or participates in studies conducted on a national level of problems affecting engineering manpower. Annual placement surveys are made for example, in order to determine the status of engineering graduates in regard to employment, military or educational commitments. The surveys made in May, 1958, covered 159 colleges with curricula accredited by the Engineers Council for Professional Development and 53 other colleges that awarded engineering bachelor degrees. In all, 16,976 graduates, categorized by curricula, were surveyed through the deans of the colleges. This number represents a significant proportion of the 1958 engineering graduates and a sample large enough to adequately evaluate the placement status as of that time. This information is made available to leaders in industry, educational centers, and governmental agencies as an aid in formulating programs and policies affecting the disposition and utilization of technical manpower.

At the time the surveys are reviewed the EMC recommends how the data should be publicized. Even the most optimistic information dealing with engineering employment may have a harmful effect if it is handled incorrectly.

The EMC maintains liaison with a number of government agencies that are responsible for policies affecting technical personnel in times of peace and emergency. The President of the EJC is a Member of the President's Committee on Scientists and Engineers; the Chairman of the EMC served as a Member of a Task Force of the President's Committee on problems of utilization of engineers and scientists; the Secretary of EMC has also served in various sub-committee posts. The Executive Secretary of the EMC is a Member of the Committee on Specialized Personnel of the Office of Defense Mobilization and is also a Member of the Executive Reserve of the ODM. This latter assignment facilitates liaison with a number of government agencies: Defense, Labor, The National Science Foundation and Commerce, to name a few.

Scientific Manpower Commission and EMC

At this point it might be well to point out that a Scientific Manpower Commission has been established for some time with objectives and goals on behalf of scientists similar to those of the EMC on behalf of the engineering profession. In 1954 these two councils began cooperating extensively and have joined forces in undertaking studies that are of mutual interest. The advantages of such a partnership are self-evident; a *Manpower Newsletter* is prepared jointly by these two Commissions, for example, and is sent to over 12,000 individuals. This Newsletter has been published continuously for five years and is widely accepted as an authoritative source of information.

There are a number of instances where this combination of forces has paid off. Basically the utilization of engineers has been and will probably continue to be the area of primary interest to the EMC. One of the important achievements in this field was the recognition of the importance of engineers to the national security by the Executive and Legislative Divisions of our government through the establishment of the Critical Skills Program. The Reserve Forces Act of 1955 and subsequent regulations directed the establishment of a maximum 6 months training period for skilled personnel employed in activities essential to the national welfare and provided quick screening from the Ready to the Standby reserves. The Critical Skills Program was suspended in July, 1957, for budgetary reasons. However, the combined efforts of the EMC and SMC led to the re-establishment of the Critical Skills Program in October, 1957.

The EMC and SMC have also supported efforts to recruit and train high school teachers and have assisted them in their important function of developing youngsters with a high potential for an engineering or scientific career. In 1957, the two groups prepared a joint exhibit of guidance material in engineering and science at the Annual Meeting of the National Science Teachers Association. The Member organizations of both the EMC and SMC contributed items of guidance material which were placed directly in the hands of the science teachers. In addition, during the year exhibits were set up by the EMC at colleges and university summer schools. Teachers taking supplementary courses or visiting the campuses were invited to request guidance material from the EMC.

The EMC has supported the activities of the Engineers Council for Professional Development by appropriating money to assist the ECPD in developing and distributing engineering guidance literature to guidance personnel in high schools.

The impact of recent international scientific developments—computers, nuclear fission, prospective interplanetary travel—on the future of technological education in the United States resulted in a Special Conference on Higher Education, Science and Technology sponsored by the SMC, National Research Council, National Science Foundation, American Society for Engineering Education and the Engineers Joint Council in November, 1957. At this conference the EMC acted on behalf of the EJC in its organizational responsibilities. The press has not been slow in capitalizing on some of the startling aspects of these scientific and engineering achievements; the proceedings of this conference were published in March, 1958, and should contribute to a more mature understanding of the problems associated with these technological developments. They are available from EJC.

EMC and College Enrollment

The EMC has been a potent force in reversing the downward trend in Engineering College enrollment. It has recognized the need for continuously improving and supporting the education of

science teachers and has assisted them in their important role as counselors at the high school level. Through its efforts there has resulted a more effective utilization of engineering manpower within the Military. It has continuously sought to educate all branches of the government dealing with scientific and engineering manpower to the mutual benefit of all concerned. Through special surveys and the medium of the EMC-SMC Newsletter the EMC has become a prime clearing house for information about engineers and the engineering profession.

In the future, we can expect an ever increasing public interest (especially at the Congressional level) in the problems dealing not only with the selection and training of students in science and engineering but also in the more urgent problems of facilities at the pre-college and college level. Certainly, one major problem will be that of providing an adequate supply of capable science teachers. The shortage of engineers—real or otherwise—will continue to receive national attention as appropriations are approved for military and space research and development projects. The EMC will play an important role in promoting the most effective utilization of engineers and providing information useful in developing plans for maintaining a supply of trained engineers in the face of these trends.

EMC and AIIE

Considering the short time that the EMC has been in existence, it has made impressive progress in fulfilling its responsibilities. The AIIE is just beginning to take an active part in the work of this Commission. In June, 1958, Herbert Ashcroft was appointed Chairman of the Committee on Government Contract Procedures and Engineering Manpower Utilization. We are in a position—through the background and experience of many of our members—to be of considerable help to the Commission in fulfilling the tasks assigned to it by the EJC.

Reported for the Professional Relations Committee
BY O. J. FEORENE

FINANCIAL STATEMENT OF AIIE

As required by Article VI, Section 28 of the AIIE Constitution, the following financial statement is published as prepared by our auditors, Keller, Kirschner, Martin & Clinger, Certified Public Accountants.

Statement of Cash Receipts and Disbursements
for the year ended September 30, 1958

CASH RECEIPTS

Dues:		
Chapter	$23,868.49	
Senior	36,882.62	
Associate	37,721.95	
Affiliate	6,545.72	
Student	3,554.80	
Application fees	7,260.55	
Journal subscriptions	6,011.34	
Sale of books, kits, and supplies	1,295.65	
Sale of jewelry	977.44	
Mailing list and miscellaneous	1,115.55	
Proceeds—8th National Conference	7,588.03	
Proceeds—9th National Conference	4,577.73	
Repayment of advance—regional conference	350.00	
Interest—savings accounts	1,090.34	
Total cash receipts		$138,840.21

CASH DISBURSEMENTS

Salaries and payroll taxes	$33,692.72	
Rent	3,247.50	
Communications	710.63	
Postage	4,181.77	
Office supplies and expense	2,674.25	
Office equipment	1,670.52	
Printing, mailing, and stationery	7,527.55	
Journal publication	25,426.01	
Travel, hotel, and meals:		
Reimbursed expense	12,140.96	
Advances	1,775.00	
Refunds—dues and fees	22,539.06	
Engineers' Joint Council	923.00	
Books, kits, and jewelry	1,878.80	
Insurance and bank charges	70.72	
Advance—9th National Conference	2,350.00	
Advance—10th National Conference	1,000.00	
Advances—chapter organization	100.00	
Total cash disbursements		121,908.49
UNEXPENDED RECEIPTS for the year		$ 16,931.72
CASH ON DEPOSIT at October 1, 1957		55,378.01
CASH ON DEPOSIT at September 30, 1958		$ 72,309.73

The cash on deposit at September 30, 1958, consists of the following:

Checking account	
The Huntington National Bank	$33,146.08
Savings accounts	
The Buckeye Federal Savings & Loan Association	10,000.00
The Dollar Federal Savings & Loan Association	9,163.65
The Ohio Federal Savings & Loan Association	10,000.00
The Park Federal Savings & Loan Association	10,000.00
Total cash on deposit	$72,309.73

The cash on deposit at September 30, 1958, is represented by:

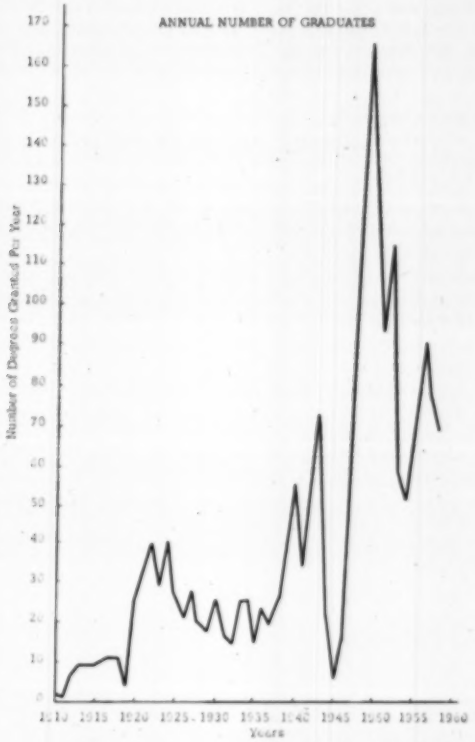
Cash received in advance for the 1958-59 fiscal year	$35,862.65
Cash received and unexpended for the year ended September 30, 1958, and prior	36,447.08
Total cash on deposit	$72,309.73

PENN STATE MARKS 50TH ANNIVERSARY OF ESTABLISHMENT OF THE FIRST INDUSTRIAL ENGINEERING DEPARTMENT

Industrial Engineering as a formal engineering curriculum is just fifty years old. In 1908 the first related courses of study in the area of Industrial Engineering were introduced in the school of engineering at Penn State. The curriculum was added as a result of a conversation at the Union League Club of Philadelphia between General Beaver, Ex-Governor of Pennsylvania and F. W. Taylor. The result of this discussion was the recommendation of

teaching "Mechanical Engineering from the standpoint of manufacturing rather than from the standpoint of power plant tests and higher mathematics."

The first class of two men was graduated with a Bachelor of Science degree in 1910. Since its beginning, 1,983 Industrial Engineers have been graduated from Penn State. The following chart illustrates this rapid and progressive growth.



—B. W. Niebel, Head, Department of Industrial Engineering, Pennsylvania State University

CHAPTER DEVELOPMENT PROGRAM

The success of the American Institute of Industrial Engineers is unalterably tied in with the success of its individual chapters. The chapters are the grass roots of AIIE.

We all recognize the fact that competition and incentive are two powerful tools of management. It behooves us then as good industrial engineers, to use these tools for the betterment of our own professional organization. With this in mind, we have established a set of standards of measurement, whereby the chapter that does the most in service to its members will reap the most in pride of accomplishment. The Chapter Development Program is that accepted standard of measurement.

The program period starts on April 1st of each year and ends on March 31st. Selection of these dates for the period of competition was made for two reasons. First, it was felt that spreading the contest year over two administrations would help us measure the chapter's ability to maintain continuity and would force them to do considerable advance planning. Second, by completing the program on March 31st, there is sufficient time to evaluate the entries, select the winners and prepare the awards in time for presentation at the annual conference banquet.

Activities of the individual chapters are measured in five fields of endeavor including organization, education, affiliation, public relations and membership. Goals are established under each of the above and point values are assigned to each goal. Chapters meeting the minimum number of points established for each of the five sub-divisions qualify for an "Award of Excellence." The chapter with the highest record is awarded the "FRANK F. GROSECLOSE TROPHY." This award recognizes the outstanding chapter in the nation and is named in honor of Col. Frank F. Groseclose, Director of the School of Industrial Engineering, Georgia Institute of Technology. Col. Groseclose has served as national president of AIIE and is a Fellow of the institute.

Last year nine chapters out of 87 qualified for the "Award of Excellence" and the outstanding chapter in the nation was the Great Salt Lake Chapter.

Very little extra work is involved in taking part in this program. As a matter of fact it amounts only to keeping score of those things that a chapter should be doing anyway if it is to operate effectively. In this, the second year of the program, about 60 of the 87 chapters are actively competing. The others are urged to take advantage of this aid for developing their chapter's operation.—*Frank J. Johnson, National Director of Chapter Development.*

CONTRIBUTED RESEARCH PAPERS FOR THE TENTH ANNUAL NATIONAL CONFERENCE

Several sessions at the Tenth Annual National Conference of the American Institute of Industrial Engineers, in Atlanta, Georgia, on May 15, 1959, will be open for contributed papers by individuals doing research in the area.

Titles and abstracts of these papers must reach Andrew Schultz, Jr., Upson Hall, Cornell University, Ithaca, New York, by April 15, 1959. The title should include: title of paper, full name and initial of the author, his affiliation and address. The abstract should be carefully prepared to indicate the essence of the paper, the purpose, what was done, and the conclusion; and it should be limited to two hundred words, double spaced, with one carbon.

It is hoped that the membership will take advantage of this opportunity to report on research accomplishments.

AIIE RESEARCH AWARDS for

- **Faculty Research**
- **Industrial Research**
- **Graduate Study Research**
- **Student Research**

Nominations and supporting evidence must be submitted prior to April 15, 1959.

Contact: Arthur F. Gould, Chairman
AIIE Research Prize Committee
Department of Industrial Engineering
Lehigh University
Bethlehem, Pennsylvania

DWIGHT D. GARDNER SCHOLARSHIP FUND

J. L. Southern, President, Dwight D. Gardner Scholarship Fund Trustees, has announced that the amount currently on deposit in the fund at the last audit was $3,168.67, and encouragement and support is continuing to expand this scholarship endeavor each month.

The trustees are conducting a yearly drive for funds in an effort to maintain the present balance and insure the continuance of the granting of scholarships each year. The amount of scholarship grant is set at $750.00, and the first scholarship is being established for the fall school term in 1959. Applications for students interested in the scholarship are available at National Headquarters and will be forwarded to individuals upon request.

The Trustees of the Fund are: J. L. Southern, President; Harold T. Amrine, Treasurer; Howard P. Emerson, Everett Laitala and F. J. Titler.

Your support through contributions will be appreciated. A partial list of contributors to date is as follows:

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E. W. Natzke and wife
Rochester Chapter, AIIE
Chicago Chapter, AIIE
F. J. Titler and wife

CALENDAR

February 12 and 13, 1959: "Computer and Data Processing in Industry" conference sponsored by Purdue University. Objective of this conference is to acquaint middle and top management with computers and data processing, including:

1. Basic concepts of computers and data processing.
2. The application of computers for answering management questions.
3. New developments in the field.
4. Case examples showing how computers and data processing can be used in industry.

March 21, 1959: Second Niagara Frontier Area Industrial Engineering Conference; campus of the University of Buffalo, Buffalo New York; sponsored by Niagara Frontier Chapter of AIIE and the Industrial Engineering Department of the University of Buffalo. Registration Fee, $12.50. Write Mrs. Ethel E. Schmidt, Director of Special Services, 172 Hayes Hall, University of Buffalo, Buffalo 14, New York.

November 4, 5 and 6, 1959: 1959 National Automatic Control Conference, Sheraton Hotel, Dallas, Texas, sponsored by the Institute of Radio Engineers Professional Group on Automatic Control, with official participation by the American Institute of Electrical Engineers, the Instrument Society of America, and the IRE Professional Group on Industrial Electronics. Technical papers are now being solicited. For information write: Mr. G. S. Axelby, Technical Program Chairman, Westinghouse Electric Corporation, Box 746, Baltimore 3, Maryland.

PERSONALITIES

GERALD NADLER

Gerald Nadler, Head of the Department of Industrial Engineering at Washington University in St. Louis, has been accorded a signal honor. He has been invited to spend some time as a visiting professor in the Department of Engineering Production at the University of Birmingham, England. During the six months he will spend in England, his general activities will include lecturing and conducting case studies in connection with graduate courses in the Department of Engineering Production, advising and assisting in the research work of the department especially on work measuring, lecturing at the Institute of Engineering Production work courses and other outside organizations, and consultation work with Joseph Lucas Ltd.

Upon leaving the University of Birmingham in June 1959, Dr. Nadler plans to spend two months touring Europe visiting various centers of Industrial Engineering activities and persons with whom he has contacts on a professional basis. September 1959 will find him at home in St. Louis.

AKRON CHAPTER

At the October meeting, Mr. Ralph W. Updegraff, National Treasurer of AIIE, spoke to our chapter on "Industrial Engineering, Past, Present and Future." Mr. Updegraff reviewed Industrial Engineering from its origin in the days of Frederick Winslow Taylor to present times, and emphasized the great challenge confronting the Industrial Engineer of today, that of helping his fellow man in all the various professions. The dinner meeting was held at the Akron Woman's City Club after which followed a lively question and answer period.

Doctor Giovanni Nassi, Chief Work Study Engineer of the Pirelli Rubber Company of Milan, Italy, and Marcello A. De Giorgis, Staff Liaison Engineer of Pirelli's New York Office arrived at the Akron-Canton Airport on October thirteenth. They visited The Firestone Tire and Rubber Company to gain an insight on American tire production techniques, work measurement, methods study, job evaluation and plant layout procedures.

Arrangements for Dr. Nassi's and Mr. De Giorgis' visit were made through the National Headquarters of AIIE and Akron Chapter President, Mr. Ralph F. Fix. During their visit to Akron, Dr. Nassi and Mr. De Giorgis were house guests of Mr. Fix.

At the conclusion of their stay, each visitor indicated a firm appreciation of the advancements made in American manufacturing, and of the vital part Industrial Engineering played in coordinating the various management functions. Dr. Nassi pointed out that Pirelli has already made advancements in work measurement of indirect labor operations at the several foreign Pirelli plants.

During his visit to the United States, Dr. Nassi was approached by one of the leading American Industrial Magazines to write an article on Indirect Labor Work Standards in the Italian Rubber

Industry. The Pirelli Company is the largest and leading rubber producer in Italy and employs approximately 22,000 people.

Mr. Fred Simon, U.A.W. International Representative was our speaker on November the nineteenth when he discussed "The Union Viewpoint on Incentives, Time Study and Job Evaluation."

Mr. John E. Schlacter, Manager of Employee Insurance & Pension Programs of the B. F. Goodrich Company spoke on "Economic & Social Impact of the Fringe Package" at the December meeting.

"Cost Control Through Budgetary Control" was the topic of Mr. Robert A. Wofsey of Arthur Young & Company, our January speaker.

Stanley D. Garthoff of our chapter received the highest grade of 77 in the State of Ohio's Professional Engineers Examination which was given last July, to the new specialists in Industrial Engineering. Mr. Garthoff is an Industrial Engineer with Goodyear Tire & Rubber Company of Akron and holds a BS degree in Industrial Engineering from Virginia Polytechnic Institute. He is a member of our Publications Committee and lives with his wife Dorothy and sixteen month old son Russell at 407 Madison Avenue in Akron.

Last year we doubled our membership and presently have 65 members with two candidates in process. This year promises to be one of the most active years in the history of the chapter.

CHATTANOOGA CHAPTER

The Chattanooga Chapter began its fourth year of activities with a membership of forty-five.

The fall schedule of meetings started on September 19th with Mr. R. A. Harrison of I.B.M., Atlanta, whose subject was "Machine Accounting." Mr. Harrison has previously spoken at regional meetings on the Industrial Engineering functions in regards to machine accounting.

The October meeting had Mr. George Parkin of Anderson-Nichels, a management consultant firm from Boston, Massachusetts. The subject was the "Industrial Engineering Aspects of Maintenance Engineering."

For the November meeting, General Electric furnished a film and speaker on the subject of "Economics of Automation."

The December meeting was designated for a plant tour. It has been found that plant visitations are a popular type of program.

Plans are continuing for our seminar. Pertinent facts available at the time of publishing are:

Time: One day seminar, tentatively scheduled for Friday, February 13, 1958.

Place: Hunter Hall at the University of Chattanooga.

Subject: "Work Measurement." It will include sessions on time study, pre-determined time technique and work sampling.

Objective: Have sessions that will appeal to both Industrial Engineers and management personnel.

The seminar will be co-sponsored by the AIIE Chapter and the University of Chattanooga.

DETROIT CHAPTER

Congratulations to our chapter officers for 1958-1959. They are: President, Chester L. Brisley; Treasurer, Max Crandall; and Secretary, Clinton A. Jaycox.

The Detroit Chapter began its new year with a discussion of Linear Programming presented at the September 9 meeting. Mr. Fred D. Stone of Peat, Marwick, Mitchell & Co. of Chicago spoke on linear programming techniques as applied to industrial problems.

At the October meeting, Mr. Floyd W. Simerson of Sears, Roebuck & Co. in Chicago was guest speaker. The title of his address was "Work Simplification, the Most Effective Tool in Today's Industry."

The Detroit Chapter is again planning a Winter Conference to be held in the latter part of January 1959. Those attending are promised a most interesting session.

LOUISVILLE CHAPTER

At our September meeting we were honored to have as speaker Mr. Delmar W. Karger, Central Regional Vice President of AIIE. He spoke to us on "The Industrial Engineer's Place in New Product Development." Mr. Karger, whi is Director of New Products Development for the Magnavox Company in Fort Wayne, Indiana, is co-author with Mr. Franklin H. Bayha of the recently published *Engineered Work Measurement*. He is an officer of the MTM Association, and active in other technical organizations including the Society for the Advancement of Management, American Institute of Plant Engineers, and the National Association of Foremen.

Dr. W. D. A. Peaslee, President of Valparaiso College, was guest speaker at our October meeting. He spoke to us most interestingly on the subject of "The Engineer in the Atomic Age."

On October 30, the Louisville Chapter sponsored a conference on "Practical Work Measurement in Material Handling." The sessions were held at the Kentucky Hotel. Members of a panel on "Brainstorming in Material Handling" included J. R. Kershner of S. A. Birn Co., G. Hedgspeth of H. J. Scheirich Co., Ralph Arboe of Famco Inc., and George Scalise of Enro Shirt Co. The luncheon speaker was Joseph Krisloff, Educational Director of the Kentucky Federation of Labor.

MEMPHIS CHAPTER

Congratulations are in order to our new officers elected at the September meeting. They are: President, Hancel C. Bonds; Vice President, Richard C. Hupp; Treasurer, George Dimit; and Secretary, Joe T. Eubanks, Jr.

Our October meeting was held at the Union Planters Bank on October 15. Joe B. Maloy, our former president, spoke to us on Linear Programming. Besides being our former president, Mr. Maloy is a Senior Engineer at Kimberly-Clark Corporation, and a licensed Industrial Engineer in the state of Tennessee. He is presently teaching subjects in Industrial Engineering at our University of Tennessee Extension.

METROPOLITAN NEW JERSEY CHAPTER

Our October meeting was an informal one, taking place in the Terrace Room of the Hotel Suburban, East Orange, on October 21. The program included five General Motors films dealing with the following topics: Making a Job Easier by Motion Study, Combining Utility With Beauty to Assure Practicality, Influencing People, A Biography of a Car, and A Miracle Occurs by Human Friendliness.

Our November meeting featured Robert Roeloffs, speaking on the subject of "Evolutionary Operation." Mr. Roeloffs, now Section Head of Operations Analysis at Merck & Co., has worked as Equipment Engineer and later as Business Office Manager with N.Y. Telephone Co. He explained Evolutionary Operation as a technique for operating an industrial process in such a way as to generate not only product, but also information on how to improve the process. It operates by introducing limited but systematic changes in controllable process variables in such a way that their effects can be identified and capitalized on. It is intended for routine use by production personnel in much the same manner as the quality control chart.

MIDDLE TENNESSEE CHAPTER

The September meeting of the Middle Tennessee Chapter was a dinner meeting at the Officers' Open Mess of Arnold Engineering Development Center in Tullahoma. Don M. Bean of the engineering branch, general services division, was speaker at this meeting. His subject was "Project Control Procedure." Members from Shelbyville, Manchester, Winchester, and Tullahoma attended.

The October meeting was held at the same location. Following the business meeting, we held our first session of Harvard University's "Business Game." Under the rules of the game, two or more companies are established on paper to manufacture and sell similar products in direct competition. At this first session, personnel for the companies were chosen and the concerns were taken through the establishment of the production lines and start of sales training. At subsequent sessions, the game will be carried on through the production and final sales procedures. Robert Koger and Cord Link, Jr., are conducting.

PHILADELPHIA CHAPTER

It is with deep regret that we announce the death of our Chapter President, Mr. Luther A. Darmstaetter. Mr. Arno Cassel will serve as President pro tempore for the balance of the 1958-59 season.

At a meeting of the Board of Directors on September 4, 1958 the following appointments of Committee Chairmen were approved: Program, Armand M. Scocca; Publicity, Michael Damroth; Membership, J. Edward Krantz; Qualifications, Ben Shatz; Constitution, William McDowell; Professional Registration, Joseph Fox; Procedures, Raymond Shirtz; Professional Relations, Edward Urbanski; Chapter Development, Albert Chaban; Regional Conference Representative, Frederick A. Cline; Chapter Historian; Vincent J. Giardina; and Special Projects, George A. Smith.

Plans for an interesting and rewarding program are nearing completion and will include monthly dinner meetings, plant tours, panel discussions and the inauguration of technical discussion groups. Monthly meetings will be held at the Engineers Club, 1317 Spruce Street, Philadelphia, Pennsylvania. Dinner will be served at 6:30 p.m. with the meeting starting at 7:30 p.m. Scheduled dates are: January 21, February 18, March 18, April 15, and May 20.

TOLEDO CHAPTER

The Toledo Chapter of the American Institute of Industrial Engineers announces its program for 1959. According to Mr. Donald A. Dettinger, President, the theme will be "Cost Reduction" with speakers and topics as follows:

In January, Mr. B. L. Hansen who is Director of Research at the National Institute of Management located in Cleveland, Ohio, spoke on "Recent Techniques in Work Measurement."

The topic for the February meeting will be "Fitting a Cost Reduction Program To Your Company's Needs." Speaker will be Mr. J. Ryan, Staff Supervisor with the A. T. Kearney and Company, Chicago, Illinois.

Mr. R. Boerner from the Textileather Division of General Tire and Rubber Company will be the speaker at the March meeting. He is Director of Industrial Relations and his subject will be "Industrial Engineering and Labor Contracts."

The April meeting will feature Mr. N. V. Reinfeld, Managing Director of the National Institute of Management, as speaker. His topic will be "Inventory and Production Control Techniques."

Following in May, Mr. W. W. Wittlinger of the Kimberly-Clark Company, Neenah, Wisconsin, will speak on "The Executive Approach to Industrial Engineering." Mr. Wittlinger holds the position of Manager of Professional Service.

The Toledo Chaper meets regularly on the fourth Tuesday of every month. Officers this year are: J. Schneider, Vice-President; F. Metzger, Secretary; and V. Caligiuri, Treasurer.

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Recent Readables

AUTOMATION

"Complete Centralized Control Is Possible Today," by G. W. McGinley, THE OIL AND GAS JOURNAL, *page 89, July 14, 1958.*

A definite move to centralize systems control in pipelining has been started in recent years. And during the last 3 years, rigorous centralized control philosophies, including provisions for ultimate automation, have been proved repeatedly in service. Hardware for such systems is available today, even in packaged form.

"First Push Button Gas Pipeline Operating Successfully," by S. Orlofsky, THE OIL AND GAS JOURNAL, *page 114, July 14, 1958.*

After more than 5 years of planning and development, Gulf Interstate Gas Co.'s system of pipeline automation is now in service. The Stanton, Ky., station, an experimental satellite unit, was the prototype for the five fully automatic centrifugal-compressor stations.

COST CONTROL

"Controlling Labor Costs in An Inflationary Period," Round Table Discussion, MANAGEMENT RECORD, *page 92, March 1958.*

Today, many companies are concerned with finding ways to reduce unit labor costs, both in the office and in the factory. This article discusses what three companies did to combat the rising costs of labor. All three have found that if a firm is to cut costs it must keep up with improved methods and make required changes when necessary. These companies believe that management can make effective use of such methods as job simplification, work sampling, work standards and scheduling.

In addition the three contributors stress the need for full employee cooperation and participation in any cost-cutting program if it is to be successful. This means that employees must understand management's problems and be fully aware that their own welfare is tied to the company's success.

"Controlling Labor Costs," MANAGEMENT RECORD, *June 1958.*

1. In a period of economic recession, the term "controlling labor costs" is often interpreted to mean cutting labor costs—sometimes to the bone. Of course, controlling labor costs does not necessarily mean cutting them directly. Nor should this control consist in panic-inspired actions taken when profits start dropping.
2. Two three-part Round Tables appear in this issue on the subject of controlling labor costs. In the first, Don F. Copell discusses "Production Wage Cost Controls"; John H Holzbog's subject is "Office Salary Cost Controls"; and A. D. R. Fraser writes on "The Medical Department's Role in Reducing Costs and Bettering Employee Relations." In the second Round Table—on the overall subject of controlling fringe benefit costs—Geoffrey N. Calvert discusses "Cost of Living Pensions"; Earl S. Willis writes on "Major Medical Insurance"; and Joseph R. Shaw's subject is "What's Happening To Workmen's Compensations."

"How to make Today's Production Controls Cut Costs In Your Plant," by H. Ford Dickie, FACTORY MANAGEMENT AND MAINTENANCE, *June, 1958.*

For the company that wants quick, sharp cuts in production costs, the author recommends the following steps: find the major area of expense, initiate a vigorous inventory reduction drive, compare measured output of various people performing the same kind of work, and speed up your educational program. In this discussion of cost-cutting production controls, he also describes the successful use of sales forecasting, mechanization, and new dispatching techniques.

"Vehicle Cost Records Pay Off," by P. F. Lecocq, MODERN MATERIALS HANDLING, *page 98, November 1958.*

1. Almost three thousand pieces of equipment are covered by cost records at the Caterpillar Tractor Co. home plant in Peoria. Ranging from bicycles to railroad cranes, these records include almost every type of mobile materials handling equipment—many of the company's own manufacture. Pay-off in this system is reflected in Caterpillar's safety record (lost time accident experience equals 2.2, four times better than the national average in heavy industry), and in reduced equipment operating costs.
2. Under this cost system areas of responsibility are clearly defined. Department heads get monthly vehicle cost reports. These costs reflect directly on departmental performance, and a poor cost report gets immediate attention. The basic reason is discovered, and if possible corrected.

"Cost Control: Look Before You Lop," Condensed from Acme Reporter, by Editors of THE MANAGEMENT REVIEW, *page 31, July 1958.*

The greatest success in cost-cutting has been achieved by companies in which top management has conditioned itself for major change and motivated front-line and middle management to gain the desired savings by methodically facing up to the problem, searching out opportunities for economies, and setting up a rational cost-cutting program. These companies have recognized that:

1. Effecting economies is not a matter of chopping off whole functions but an over-all process that extends through a whole company.
2. More often than not, successful and relatively painless cost reduction means a revision of a system, or the development of some formal procedure where none existed before.
3. Record keeping in all departments and at all levels is especially vulnerable to the scalpel of the cost-conscious executive, but the probing has to be done in depth.
4. There are no standard cost-cutting formulas, for one firm's waste motion may be another's essential function. Tracking down excess cost depends on a clear answer to the question, "What are our real needs in this particular company?"
5. Cost cutting is a team job. Unless the achievement of savings is a goal of the total enterprise, the effort will be only partly successful.
6. Administering the program is a tougher job than getting cost-paring ideas, because vested interests will often be affected. Cost-cutting tools—data showing how the cost dollar breaks down—must be available down to the lowest levels, and all responsible personnel must be trained in using them.

GENERAL

"How to Work with Committees," by D. W. Blend, THE IRON AGE, *page 73, July 10, 1958.*

1. Management's primary function is to make the best use

of the abilities of the people in its organization.

2. Much has been written and spoken about the various management systems. The fact of the matter is that most management systems will work if the people involved want them to work. It is not the management system that is important, but people's attitude towards the specific system. Every system of management involves some use of committees in one way or another.
3. Sooner or later, there must be a committee meeting.
4. Here are some of the things to keep in mind in using management committees, to get the best results, and also avoid some of the pitfalls.

"Technical Writing by Engineers," by M. K. Bonner, MACHINE DESIGN, *page 90, June 16, 1958.*

The author and the editors of *Machine Design* recently conducted a survey to gage the amount of writing being done by engineers and the management policies and opinions concerning technical communication. As expected, the vast majority of firms are in favor of writing. An analysis of some of the whys and wherefores of the situation have led to suggestions for its improvement.

"The Modern Office—Industry's New Profit Frontier," by T. Kenny, DUN'S REVIEW AND MODERN INDUSTRY, *page 49, September 1958.*

This is a six part feature covering:

1. "Today's Office—Room for Improvement." Big changes are taking place in office operations as companies plan for the rich markets ahead in the next decade.
2. "How Much Mechanization Can You Use Profitably?" Here's a rule-of-thumb guide to proper office equipment for paper work jobs of various types and sizes.
3. "New Survey Spotlights the Office In Transition." A survey of detailed office plans and procedures reveals far-reaching changes are now taking place.
4. "The Office: A Better Place for Better Work." A look inside modern offices that are giving management a competitive edge in a profit-tight economy.
5. "Getting Down to Cases." How companies are getting better and faster information by taking advantage of the latest in equipment.
6. "New Horizons in Manning the Office." Modern office operations demand specialized skills. How has the clerical personnel picture changed—and what lies ahead?

"Statistical Aids to Decision Making," by C. A. Bicking, INDUSTRIAL QUALITY CONTROL, *page 7, August 1958.*

This article describes a direct application of probability concepts to management decisions. The basic principles used are similar to those applied in statistical quality control and design of experiment at operating and technical levels of business. A general pattern of analyzing problems, described popularly as Design for Decision, has been applied to real examples of decision making.

The aim is to combine careful estimates of costs and of returns with equally carefully estimated probabilities of the occurrence of various outcomes of alternative courses of action. When costs, returns and probabilities are combined, the value or desirability of the alternatives are expressed in quantitative terms. A comparison of the desirabilities of the several possible courses of action enables the manager to choose the most favorable one.

"Taylor's Message For Today's Managers," by Dr. Ir M. G. Ydo, ADVANCED MANAGEMENT, *page 5, March 1958.*

1. Taylor's techniques are understood, but not his aim. And these techniques—for instance, timestudy—can be used for different purposes. Because people did not understand Taylor's purpose, they used his techniques in a different sense than Taylor intended them to be used, and this resulted in the "Taylorsystem," which does not fit Taylor at all.
2. After a thorough study of Taylor's work and his life, the author came to this conclusion: that the techniques which Taylor developed are more often used to enlarge profits than to form the characters of the workers.

"Looking Around," by R. F. Ericson, HARVARD BUSINESS REVIEW, *page 143, September-October 1958.*

In the philosophy of business one of the most heated battles now going on concerns the question as to whether management should be autocratic or whether some of the newer, more participative patterns are needed. The battle between the old-school "realists" and the new "radicals" and "idealists" is, of course, an intensely personal one to many executives, and the fact that the argument is often carried on by social scientists and philosophers does not lessen their involvement. The author takes sides with the "idealists," but his article should be of value to businessmen in both camps since he has emphasized helpful sources of information, particularly those dealing with the central values and assumptions underlying the argument.

"How to Set Up a Preventive Maintenance Program," by Frederick D. Manning, MILL & FACTORY, *January 1958.*

It may take several years to get a preventive maintenance program running smoothly, says the author, but the effort will be rewarded by reduced maintenance costs and increased production time. He outlines a step-by-step procedure for setting up such a program, including:

1. Making permanent records on all equipment.
2. Establishing the organizational structure of the program.
3. Planning the use of Maintenance manpower.
4. Preparing inspection schedules.
5. Setting up effective controls on Maintenance supplies.

"Effective Communication Depends on the Listener," by P. Talovich, THE OFFICE, *page 71, October 1958.*

The author states that one of the most important factors to effective communications is a receptive listener.

The failure to communicate arises because the prevailing attitude inhibits the listener and causes him to suppress his desire to seek clarification by asking questions or by advancing suggestions. This attitude, manifested however subtly by his superiors, causes the employee to feel that he is an "Outsider" and is apt to be "put in his place."

To determine the effectiveness of communication, some test should be made of the penetration level. At what point did the listener fail to comprehend the issue? What is the essential element? These questions can be answered only by the listener. He will provide the necessary clues only if he is given an opportunity and an environment in which he can ask questions and advance suggestions freely without fear of rebuff or ridicule.

"Moral and Ethical Standards in Labor and Management," NATIONAL ASSN. OF MANUFACTURERS, *2 East 48th St., New York 17, 8 pages, Free.*

Cites the self-imposed obligations of business management and organized labor to the general public, to people as individuals, and to the nation's economy. The NAM code of ethics and credo and the ethical practices code of the AFL-CIO are at odds at some points.

"Job Design—Meeting the Manpower Challenge," by Dr.

George H. Hieronymus, SOCIETY FOR PERSONNEL ADMINISTRATION, *Pamphlet No. 16, January 1958.*

Today's scientific and professional manpower shortage can be greatly diminished by improving our utilization of human resources already available. Alteration of job patterns and duties so as to utilize only an individual's highest talents and to release him from tasks with substantially lower skill requirements "will increase our manpower and skillpower without costly college recruiting campaigns, and without proselyting among other employers." The author includes helpful hints and suggestions for implementing this sort of job engineering.

INVENTORY CONTROL

"Determining the Best Possible Inventory Levels," by K. J. Cohen, INDUSTRIAL QUALITY CONTROL, *page 4, October 1958.*

The author is concerned with the problem of how inventory levels should be established. This is an important problem, for inventories play a role in all phases of business and industry, whether retail, wholesale, or manufacturing. Rather than considering all aspects of inventory problems, however, the author concentrates on the function of inventories in the distribution of commodities, in particular, in the wholesaling operations, and not with the part that inventories play in manufacturing.

"It Pays to Control Inventories," THE IRON AGE, *page 46, June 12, 1958.*

1. Inventory turnover as a measure of inventory management efficiency is being used by some companies.
2. John A. Patton Management Engineers have used turnover in setting up an inventory control system for a jobber of oil country equipment, applying it to finished goods only. Inventory on hand at the start of the year is deducted from cost of material sold during the year. Year-end inventory is then divided into the cost of material sold to get an inventory turnover figure.

"Simple System Keeps Tab on Inventory," by Editor, CHEMICAL WEEK, *page 59, Sept. 20, 1958.*

A simple statistical method is the heart of a system that General Electric is adopting to control inventories of its insulating materials department's products. Originally developed for inventory control of some silicone products, the method is now proving successful in reducing reliance on individual product sales forecasts, establishing a stockout level attainable through inventory control, closely gearing stock levels to actual sales and in limiting the occasions when a product is out of stock.

MATERIALS HANDLING

"Materials Handling," CHEMICAL PROCESSING, *page 33, March 1958.*

"No one can overstress the importance of material handling as a means for combatting today's high operating costs . . . top management is well aware of the need for even more improvements (in material handling operations) in the competitive period ahead," says Francis M. Anable, Victor Chemical Works' vice president, in the article opening the feature on material handling.

In addition to Mr. Anable's article discussing top managements approach to solving material handling problems, there are articles discussing the engineering, financing, purchasing, and other managing aspects of material handling operations in the chemical processing plant and the five major fields of material handling equipment.

"Pallets For Interplant Shipping," by J. E. Wiltrakis, MATERIAL HANDLING ENGINEERING, *page 72, November 1958.*

Systems engineering is essentially a method of viewing the whole problem so that you can set up factors to be studied in a logical sequence. The relationships of these factors are developed and faster, lower cost methods are sought. In this article, the author applies systems engineering to an area where opinions are many and facts few.

OPERATIONS RESEARCH

"How You Can Use Linear Programming," by N. V. Reinfeld and B. L. Hansen, MILL & FACTORY, *December 1958.*

In the opinion of the authors, linear programming is a versatile mathematical tool that can provide accurate, quick answers to knotty problems of scheduling, inventory control, tooling, material handling, peak demand, distribution, etc. After describing the type of problem that can be solved by the technique, the authors gave detailed examples of how it is used in such production areas as machine scheduling and scheduling tooling set-ups.

QUALITY CONTROL

"Quality Control In An Electrical Service Industry," by T. G. LeClair, INDUSTRIAL QUALITY CONTROL, *page 9, April 1958.*

While to many it might not appear that the techniques of quality control would be particularly applicable to an electric service company, the author tells about several phases from actual material control to load factor analyses where quality control has already been used and numerous other areas where they are planning to use it to hold down costs and hence electric service rates.

"Quality Control of Inventory Turnover," by L. B. Kahn, INDUSTRIAL QUALITY CONTROL, *page 4, April 1958.*

Statistical analysis and control charting is described, not for conducting an inventory count, but for analyzing the activity of items in an inventory. The author presents a formula to determine an index of activity for each item and shows how it is used to pinpoint items of extremely high or low activity that require management action.

"Quality Control in Action," AMA MANAGEMENT REPORT NO. 9, *price $3.00, AMA Members $2.00.*

In this report, managers with a wide range of quality control experience describe top management's responsibilities and functions in quality control; how to organize a quality control program; how to design quality into the product; how to reduce the cost of control; and some frontier applications of quality control. The papers of which this volume is comprised are based on material originally presented at a special conference on "Quality Control in Action."

"Design and Operation of a Double-Limit Variables Sampling Plan," by A. J. Duncan, JOURNAL OF THE AMERICAN STATISTICAL ASSOCIATION, *page 543, June 1958.*

The paper presents and illustrates the use of three charts and a table for the design and operation of a double-limit variables sampling plan. Two of the charts are plots of the Lieberman-Resnikoff tables of the minimum variance unbiased estimate of the proportion of a normal universe exceeding specified limits given sample estimates of the mean and standard deviation or average range. The table is an extension of the Patnaik table of conversion factors for use of the average range in lieu of the standard deviation.

WORK MEASUREMENT

"Only Work Measurement Can Set Fair Day's Work and Pay," by Dr. L. J. Rago, THE OFFICE, *page 130, October 1958.*

Although offices make limited use of work standards (estab-

lished by stop-watch time studies), they constitute one of the many useful means of achieving office efficiency. Through the intelligent application of carefully developed output quotas (work standards), a fully objective appraisal of employee performance and effectiveness can be made. The primary achievement of output quotas is that they help the office supervisor exercise control over working habits of the office force. Thus, a basis for an equitable distribution of office workloads is provided.

"Measuring Clerical Data For Measuring Office Work," by Editors, THE OFFICE, *July 1958.*

1. A work measurement technique for reducing office and clerical costs as much as 30% has been developed by Serge A. Birn Co., a management consulting firm.
2. The procedure will also control and balance clerical and office work loads as well as measure individual performance. Called Master Clerical Data, or MCD, the studies are based on Industrial Engineering principles, heretofore used on the production line, but now made applicable to office work measurement.
3. Using MTM as the basic tool, engineers on many different office jobs collected and assembled MTM standard data for all clerical work. The job has been practically completed, and they have found that about 90% of all clerical work is performed with time values that are constant. This Master Clerical Data (MCD) now comprises a list of standards elements used to perform all kinds of office work not requiring creative thinking. A trained office supervisor can put these basic elements together to compute a standard for most clerical jobs. No engineering background is required.

"Setting Standards For Jobs That Require Mental Decisions," by A. E. Fain, THE OFFICE, *April 1958.*

There are four basic steps in establishing standards for office operations:

1. Introduce and indoctrinate supervisors and employees.
2. Determine what is being done.
3. How often is it done? Answers must be obtained concerning the total volume of the work processed during a typical month or week.
4. Determine the normal fair time allowance for an average employee working at a fair rate of speed.

These basic rules of approach form a background for the answer to the introductory question—"How can standards be established for tasks requiring judgment?"

Thought processes occur simultaneously with mental and physical actions such as reading and writing. While we are reading or writing, we are also simultaneously evaluating and judging. The accuracy of judgment does not require a separate time period devoid of all physical effort whereby we can sit back and arrive at a decision. It does, however, require that full and ample time be allowed for reading or listening to all information pertinent to arriving at a decision.

"Time Measurement Provides Supervisory Control Standards," by A. E. Fain, THE OFFICE, *September 1958.*

Rising costs, increased complexities of paperwork and the shortage of competent clerical personnel are major business problems which call for major solutions. There are two prime approaches through which management can obtain improved operations. The first, and most glamorous, is the electronic computer which does much to provide more information at less cost. There is a second approach which also can produce substantial savings without capital expenditures for equipment. This is the use of control standards developed through uniform time measurement.

WORK SAMPLING

"Work Sampling For Measuring Clerical Work," by J. A. Ritchey, THE OFFICE, *page 96, November 1958.*

The application of work measurement to clerical activities is difficult at best, but its difficulty does not make it less desirable or less necessary as a means of determining the amount or kinds of work performed on office jobs. The difficulties present challenges, rather than reasons for despair. It is the author's purpose to show how these challenges can be met, in some cases, through the use of work sampling.

"The Use of Random Work Sampling For Cost Analysis and Control," by A. C. Rosander, H. E. Guterman, and A. J. McKeon, JOURNAL OF THE AMERICAN STATISTICAL ASSOCIATION, *page 382, June 1958.*

Random time sampling of activities (work sampling) is successfully applied to everyone in a division of 350 employees for the purpose of budget planning and cost control. To insure this success several technical and administrative problems had to be solved, especially those relating to the design and management of the sample. An appropriate model is described together with methods of sampling, estimating, and calculating sampling errors. Bias is reduced by using an employee instruction booklet, anonymous reporting, and by classifying and coding activities. Cost of the plan is reduced by using a stratified cluster sample, a check-type data sheet, a simplified method of estimation, and by calling random times by telephone.

BOOKS

IDEAS FOR MANAGEMENT, *Systems & Procedures Assn., 4463 Penobscot Bldg., Detroit 26, 500 pages, $16.00.*

The papers and case histories presented at last year's International Systems Meeting, comprising 80 articles by well known systems executives. Included is the Systems Panorama which is particularly suited to the individual who handles a systems function along with other duties and to management executives who must keep pace with today's fast moving trend in systems and procedures. The Systems Manager Seminar, another section of the book, answers many of the day-to-day problems which face managers of a systems department; how to train a systems analyst; how to plan, schedule and justify systems work; how to maintain an effective staff organization, etc. This book is offered on ten-day approval.

LINEAR PROGRAMMING: FUNDAMENTALS AND APPLICATIONS, *by Robert O. Ferguson and Lauren F. Sargent, McGraw-Hill, 330 West 42nd Street, New York 36, 360 pages, $10.00.*

Written for executives and managers at all company levels and illustrated by examples from industry, this book demonstrates what linear programming can do and the results it can bring. Without going into higher mathematics, the authors have taken a complex technique and presented it as a practical planning tool, with clear treatment of the fundamentals, methods and applications. The book contains two new computational methods developed by the authors, plus a time-saving refinement, called MODI, of an existing computational method also developed by them.

i.e. opportunities

WHAT IT IS

The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Columbus, Ohio chapter.

SERVICES PROVIDED

Current job openings are published in condensed form in each issue.

In addition, a monthly I. E. Opportunities Bulletin is supplied to over seventy chapters located throughout the United States.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

Industrial Engineers are often employed in such fields as Work Measurement, Production Control, Plant Engineering, Operations Research, Industrial Relations, Sales, and Management.

For a more complete coverage, see the following list of job classifications. Please do not hesitate to forward information on jobs in any area where it is recognized that an Industrial Engineering background will be of value.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

This information will be publicized to the members in condensed form in the JOURNAL and in monthly chapter Bulletins. Company names are not shown.

MEMBERS SEEKING JOB OPPORTUNITIES

The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

ADDRESS OF THE SERVICE

I. E. OPPORTUNITIES SERVICE
American Institute of Industrial Engineers
145 North High Street
Columbus 15, Ohio

INDUSTRIAL ENGINEERING OPPORTUNITIES

Position number	Industry, location		Travel?	Job classification number (See key)	Salary	Qualifications required			
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range	
								from	to
6	Warehouse	N.J.		94					
17	Air Force	O		11, 13, 42, 31, 38	8.8		4–5		
23	Education	NY		10, 50	6–10				
31	Paper Mill	Wis		11, 45, 80, 70, 32			1–5		30
41	Consulting	O	×	10, 21, 31			5–7		
72	Airline	Ill		70, 42, 43					
79	Mining & Smelt	NM		10, 20, 30, 40	6–9				45
93	Foundry	Ill		15	8.4		5	25	40
119	Paper	Ga		10, 20, 30, 42, 43, 53	6.0–7.2				
123	Printing	NY		49, 53			2–4		
145	Lithography	Vt		31			2		
155	Electronics	Texas		11, 13			3–		
167	Weapons Systems	Wash DC		50		Ph.D.			
172	Power Shovels	Pa, Wisc, Ind		11, 13, 21, 32, 39					
177	Education	NY		50+Gen. I.E.		M.S. or Ph.D.			45
181	Bldg. Maint.	Mich		31, 38, 48					
197	Aircraft	Wash		I.E.	6–11		2	25	40
198	Paper Converting	Mo		10, 11, 13, 19, 71	6–		5	30	40
199	Govt. Agency	Panama		Engr. Trainee	5.6–6.7			20	
200	Electronics	Texas		11, 31, 33, 35, 38, 54, 70	7.2–9.6		3–		
202	Electronics	Texas		11, 19, 33, 35, 38	6.5–8.0		5–		
203	Electronics	Texas		11, 19, 38	7.2–8.6				
209	Consulting	Ill-NY	×	50, 51, 52	9.0–15.0				
210	Mfg.	NY, NJ, Fla, Cal, Ill		54, 50 (Military)	10.0–15.0				
213	Aircraft Repair & Mod.	Cal		15, 32, 42, 43, 44, 53	7.5		2½	21	
214	Airforce Depot	NY		13, 31, 40	4.4–7.4				
223	Navy Ship Repair	Guam		94–42, 44, 48, 49	7.5 plus 25%				
228	Navy Overseas Bases	Pacific		Preventative Maint.					
229	Bakery	[illegible], Cal							
244	Steel Ind.	Mich		10, 11, 13, 15, 21	5.3–5.8		0–2	23	33
246	Paper & Bag	Ala		33, 34, 35, 51, 54, 71, 73, 91					
247	Navy	Guam		92–13, 36, 42, 48, 70	8.8		3		
249	Chemicals	WVa, Cal					5	25	35
257	Chem. Proc.	Pa, WVa, Va		10, 21, 43	Open		1–5	Open	

Position number	Industry, location		Travel?	Job classification number (See key)	Salary	Qualifications required			
					Range in $1,000	Adv. degree req.?	Years of exper.	Age range	
								from	to
267	Electronic Supply & Eng.	NY		10, 30, 40, 70	4.5–7.5		3		
271	Syn. Fibers & Films	Pa, Va, WVa		10, 20, 42, 43			0–5		
273	Air Force	Utah		10 through 19	6.3–7.5		1½–2½		
274	Maint. Control	SC		11, 18, 52, 71, 90	7.5–8.2		2½		
275	Maint. Control	SC		11, 18, 52, 71	4.4–4.9		0		
278	Retail Chain	O		30, 42, 43, 71					35
279	Airline	Ill, Colo, Cal		11, 13, 42, 43, 70	5.0–8.0		2–8		
281	Education	Mo		10, 31					
282	Chemical	Fla		10–19, 30–39			–5	27	33
288	Electronic	Tex		11	7.2–8.2				
289	Electronic	Tex		70	7.2–8.2				
290	Electronic	Tex		19, 36, 38	7.2–8.2				
291	Electronic	Tex		11, 13, 15, 16, 91	8.6–10.0				
296	Research	Cal		42–45, 50–55	8.0–12.0		2–5		
298	Pulp and Paper	NC		35					
299	Education	Mass		10, 20, 30, 40, 50		M.S. or Ph.D.			
300	Consulting-Mfg.	Nationwide	×	10, 11, 29, 31, 36, 42, 71	8.0–20.0	B.S.–Prefer M.B.A.	7–	28	38
301	M. Consulting	Upper Midwest	×	Broad	10.0–14.0		5–	28	50
302	Missile Production	Wash		10, 30, 40, 50, 70	6.0–11.5		1–		
303	Air Force Depot	NY		13, 31, 40, 91	4.4–7.5		0–3		
304	Mail Order House	Wisc		15, 81, 94			3–		
307	Automotive	Pa		52, 54, 70	6.6–9.6		4–6		
308	Automotive	Pa		19, 36, 38, 53	6.6–9.6		4–6		
311	Aircraft	Cal		11, 13, 15, 18, 33, 34, 35, 42, 43, 44, 47, 54, 71, 91, 92			5–		
312	Chemical	Colo		10, 11, 13, 36	6.0–8.4		0–5	22	35
313	Aircraft	O		42, 43, 44, 34, 18	5.4–7.2		1–	24	42
314	Mfg.-Steel PrMd.	O		36, 39, 48, 80, 97			5–10	25	35
315	Air Force	Cal		10, 13, 15, 32, 38, 42, 43, 44, 53	5.4–7.5	1 yr Spec. Field	2½	21	
316	Mining	Nev		10, 20, 30, 40	6.0–9.5			21	45
317	Mgmt. Consulting	NJ		10, 20, 31, 42, 54, 70	8.0–12.0		5	30	45
318	Wood & Plastics	Va		10, 11, 14, 15, 16, 18, 22, 21, 23	8.0–10.0		3–5	28	38
319	Alum. & Chem.	Cal, Ill, Ind, La, Md, O, Pa, RI, Wash, WVa, Jamaica BWI		11, 53, 18, 36, 38	6.0–9.0		2–5	25	35
320	Alum. & Chem. (Same states as above)			91 or 92	10.0–14.0		6–10	32	45
321	Steel	Ontario		10, 11, 21, 38, 91, 26					
322	Steel	Ontario		10, 11, 38					
323	Steel	Ontario		50, 54					
324	Steel	Ontario		10, 11, 21, 42					
325	Steel	Ontario		38, 53, 49					
326	Steel	Ontario		10, 13, 14, 15, 21					
327	Education	Fla							
328	Research & Edu.	Pa		26, 61, 64, 65					
329	Metal-Mach.	Mass		32, 36, 39	14.0–16.0				
330	Electro-Mech.	O		10, 16, 19	8.4–9.6		4–8	30	
331	Plumbing Goods	WVa		10	4.2–4.8				
332	Printing	NY		11, 13, 18, 36, 37, 42, 43			5		35
333	Edu. (Wood Prod.)	NY		30, 37, 40					
334	Education	Fla		10, 26, 31–36, 40–45, 53, 66					
335	Syn. Fibers	Ala		10, 11, 26, 70			3	30	
336	Steel	Mich		38	8.0–10.0		2–5	25	35
337	Research & Devel.	NJ		11, 13, 42	6.2		2–3		
338	Steel	Mich		10, 11, 19, 36	–6.0			25	35
339	Automotive	Pa		11, 13, 15, 16, 22, 23, 36	6.6–9.6		4–6		
340	Automotive	Pa		13, 14, 15, 16, 22	5.4–7.8		0–2		
341	Printing	NY		10, 11, 22, 32, 42, 43	7.8–9.5		3–5		
342	Com. Refrig.	NJ		10, 13, 14, 15, 20, 21, 22	8.0–11.0		8–10	30	40
343	Com. Refrig.	NJ		31, 32, 33, 34, 35, 94	8.0–10.0		10–12	30	40
344	Hosiery	NC		10, 11, 30	4.6–6.0		2–5	25	45
345	Govt. Agency	Wash DC		10, 11, 42	8.2				
346	Education	Ga		19, 53, 51 (Research)	7.0–10.0	Degree M.S. or Ph.D.	2–5	30	45

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic
16	Predeter. Elemental Time Stds
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

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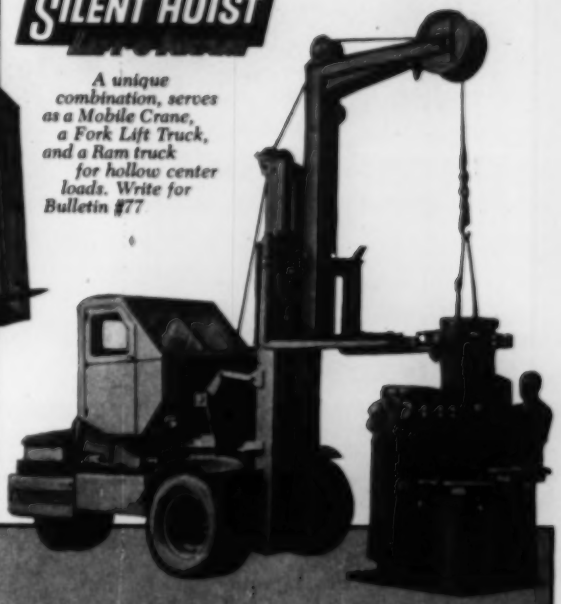

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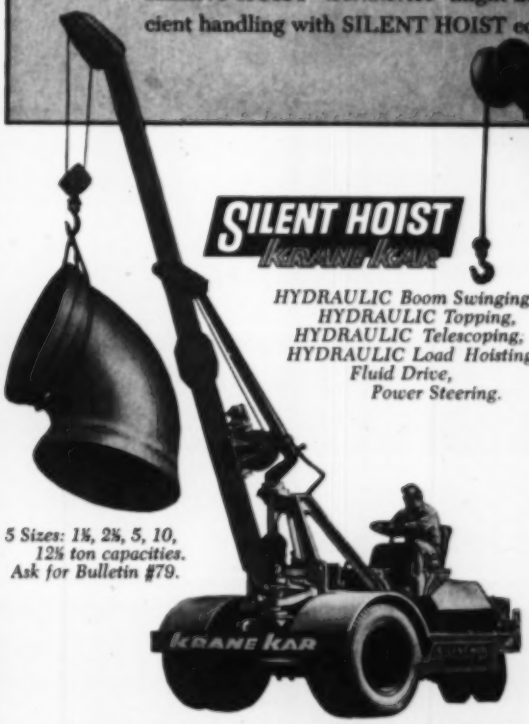

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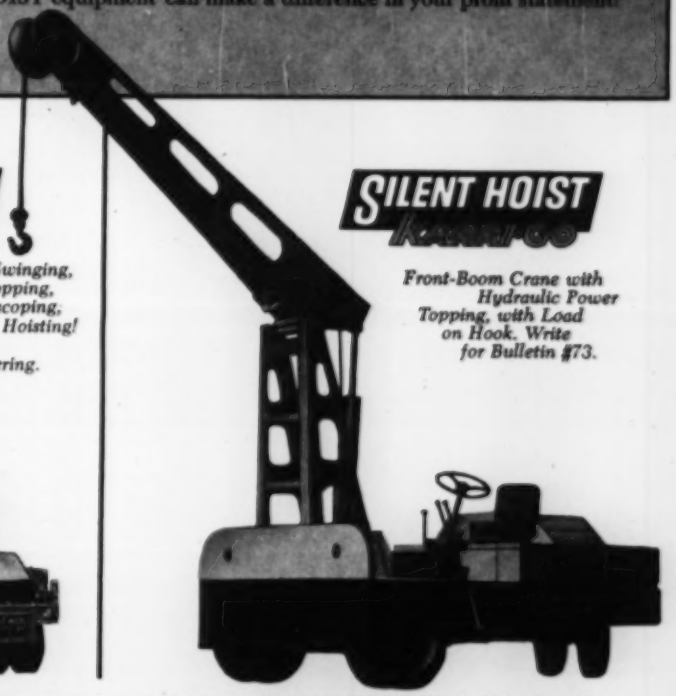

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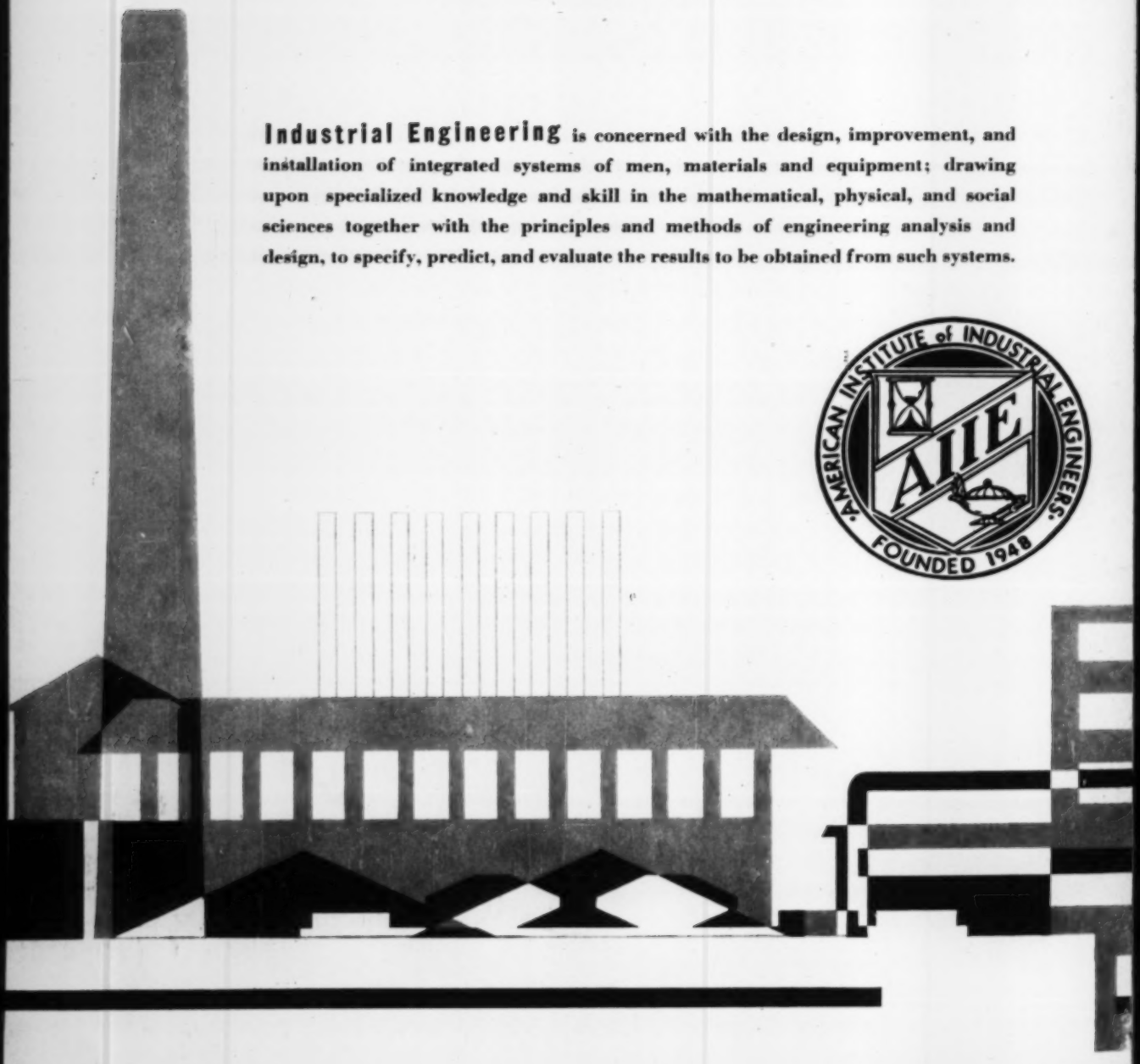
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